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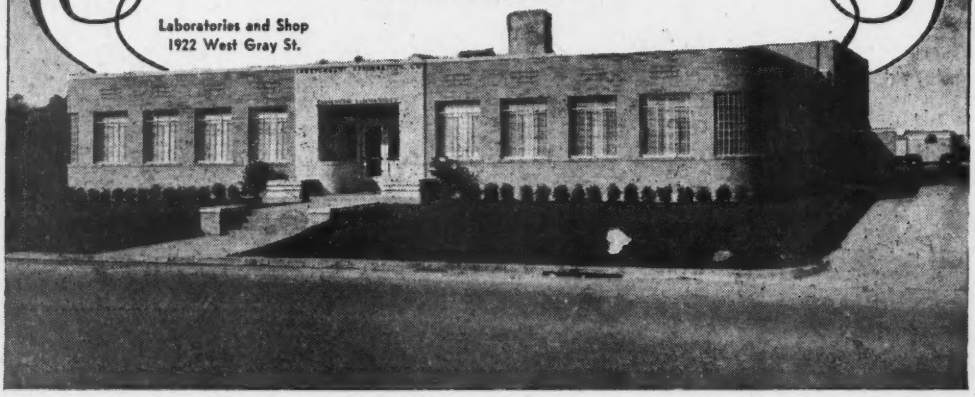

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VOLUME IX OCTOBER, 1944 NUMBER 4

GEOPHYSICS

A Journal of General and Applied Geophysics

HOW *NOT* TO FIND AN OIL FIELD*

JOHN SLOAT†

ABSTRACT

This paper discusses causes and cases of seismograph misinterpretation, with examples of errors resulting from certain spreads, from weathering computations, and from incorrect velocity assumptions. The question is raised as to whether subterranean weathering corrections, echo reflections, transverse waves or regional velocity gradients have caused serious mis-mapping of structure. The evaluation of results from dip shooting is reviewed, with cases showing how oil fields have been missed.

The psychological factor in picking records is stressed and the use of marked records in correlation is questioned. The need for a better criterion of correlation is expressed, and it is suggested that a more complete study of results might result in fewer dry holes.

We geophysicists like to speak with pride of the correct correlations we have made and the oil fields we have found. We gloat with glee when the drill reveals a fault we have predicted, but are prone to forget the cases where the drill disproves a fault, or where the drill says *up* where we said *down*. We forget the case where we had a flat dip or two, failed to check them, and Company X found an oil field (this, of course, was the fault of the geologists—they didn't want to spend the money to shoot continuous spreads), or the case where we showed a little closure from incomplete data or study of the records, and the drill found the "high" barren (this, too, was the geologists' fault—they insisted on using that erratic dip to make closure). Then, too, how about the case where we ran a line between those two wells and put in a fault to tie, and it later turned out that there was no fault but that our velocity chart was off a thousand feet at one of the wells?

You may say that it is human nature to forgive and forget our

* Read by title at the fourteenth annual meeting, Dallas, Texas, March 1944.

† Union Oil Company of California, Bakersfield, California.

mistakes. Some may contend that otherwise the conscientious interpreter will develop a defeatist attitude and be afraid to put down a doubtful correlation which may prove to be correct. To some extent this may be true, but probably very few geophysicists have a defeatist complex. Most of us are conceited enough to think we know just a little more than the next fellow about mapping structure. It might do us all a lot of good, then, if we would look into our mistakes (whether we admit them or not) and search for the answers to our errors. In so doing, perhaps next time we can at least avoid the same pitfall, and rely on a fresh alibi to explain any new misinterpretations.

The following list of mistakes which many of us have undoubtedly made with the seismograph is not complete, but may encourage the revelation of a few others and help us all to see why they were made. Miscomputations and other run-of-the-mill errors are not considered, as it is assumed the computers were awake that day and that the party chief was sober. The mistakes considered here are principally the ones which sneak up on us unawares and result either in our showing the wrong relief or in overlooking a structure. Perhaps you prefer to call these injudicious estimates, rather than mistakes.

I. MISTAKES RESULTING FROM TYPE OF SPREAD USED OR HOLE SPACING

You may remember that in the early days of reflection dip shooting many companies used single-end or end-on spreads, with holes 2000 or 3000 feet apart. Each hole was shot in opposite directions along the line, and the dips on the opposite sides of the hole were found by subtracting the weathering correction and "normal" move-out from the record move-out, with the residual then being converted to a tangent.

When these resulting dips were plotted, the cross-section often appeared to have a syncline at every shot point as though the underground had been given a permanent wave. The 1935 cross-section shown in Fig. 1 is a fair example of this sort of thing. We soon learned that this effect was caused by errors in the assumed velocity used in constructing the normal move-out chart. It then became common practice to average either the move-outs or the tangents from opposite sides of the same hole so that the cross-section showed the same dip for the two sides, thus (theoretically) averaging out the error in normal move-out. This, too, was dangerous because in some cases there was actually an anticline or syncline present which was erased.

You may say that this is ancient history—that no one shoots like

that today. Nevertheless, many of us have gradually returned to a modification of this scheme in present continuous shooting. We place our holes 1000 to 2000 feet apart and shoot single-end or end-on profiles continuously down the line, giving so-called continuous subsurface coverage. The profiles are computed in pairs with the move-out or

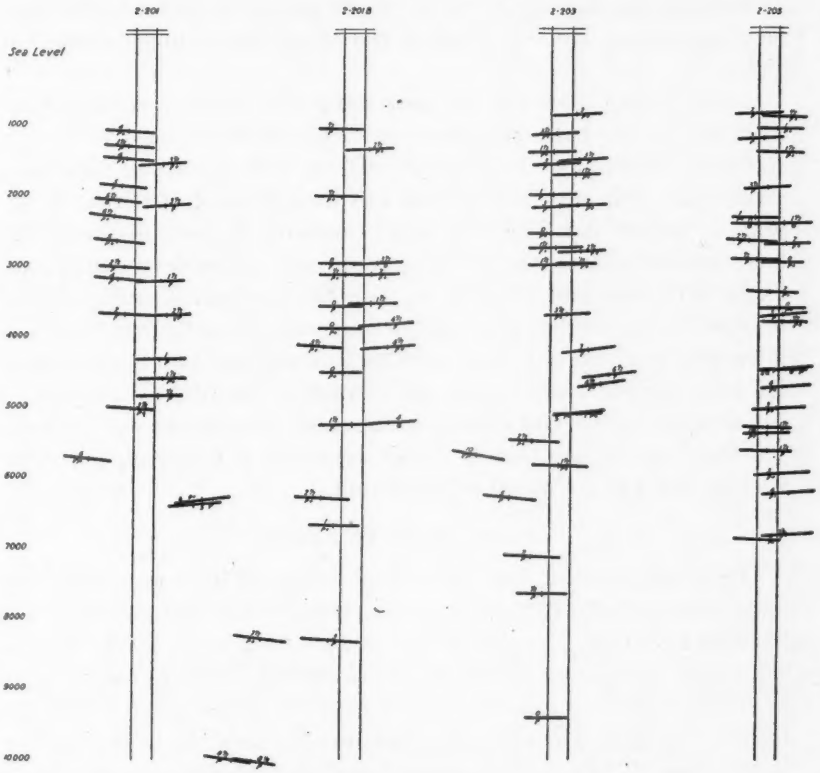


FIG. 1. Velocity error in "normal move-out" chart caused these single-end spreads to show a syncline at every hole.

tangent being averaged to obtain the dip between holes. This works fine until the going gets tough and one side has reflections which do not appear on the reverse profile from the next hole. When this happens we are back where we were with the early work—the accuracy of such dips (assuming reliable picks) will depend on the accuracy of our velocity assumptions for the area. This is an important point, particu-

larly in areas of poor results where reliance is placed primarily on dip projection in making the maps. It is important that we realize what type of spread was used before we use these unmatched dips in showing a nice closure, nose or fault.

One way to avoid this trouble is to shoot split-spreads across the hole, or offset from the hole. But this will require twice as many holes if the same length spread is used; if the spread is doubled, this may require too much cable or result in too long a spread to get consistent picks.

I recall one case where we were using continuous end-on spreads with some of the holes 2640 feet apart. The line computed to be generally southwest dip, with dips between one pair of stations appearing rather flat. This was noticed but was interpreted to be what it appeared—merely flat. Unfortunately, Company B shot this line using holes 900 feet apart—and not even continuous subsurface—and found a nice little anticline between our two flat stations. A small oil field resulted. Since our dips and depth points were obtained over 2640 foot intervals, we could not know that an intermediate point was higher, for intermediate traces were not computed because of absence of weathering control. Our alibi was that there was a water well between the 2640 foot stations that we didn't want to buy. Company B bought a water well but got an oil well in return.

II. WEATHERING ERRORS

Here is a problem: Assume a line of holes shot in an area where the underground beds are known to be perfectly flat and the surface is likewise flat at an elevation of 60 feet above sea level, as sketched in Fig. 2. Let us say that the depth of weathering in hole #3 computes to be 60 feet deep and holes #2 and #4 compute 30 feet deep from first-break refraction intercept plots. Assume the velocity of the low velocity zone at 2000 feet per second and that of the unweathered at 6000 feet per second, as shown from the refraction plots and up-hole information. A correlating reflection on hole #3 shows a record time of 3.000 seconds to a shot depth of 60 feet, with the same reflection coming in on holes #2 and #4 at a record time of 2.995 from 30 foot holes.

Now compute the depth of the bed in each hole by referring the reflection time to the depth of weathering in the usual manner. The time below datum in hole #3 will be 2.970 seconds and holes #2 and #4 will be 2.980. Using a run-of-the-mill velocity chart, we get a subsea

datum in hole #3 of 14,039−0=14,039, while holes #2 and #4 show the bed to be 14,109−30=14,079 below sea level.

Thus we show a nice 40 foot high on hole #3, yet the bed is actually flat! This is a familiar problem to many geophysicists, yet it always seems impossible at first sight because it seems this difference should

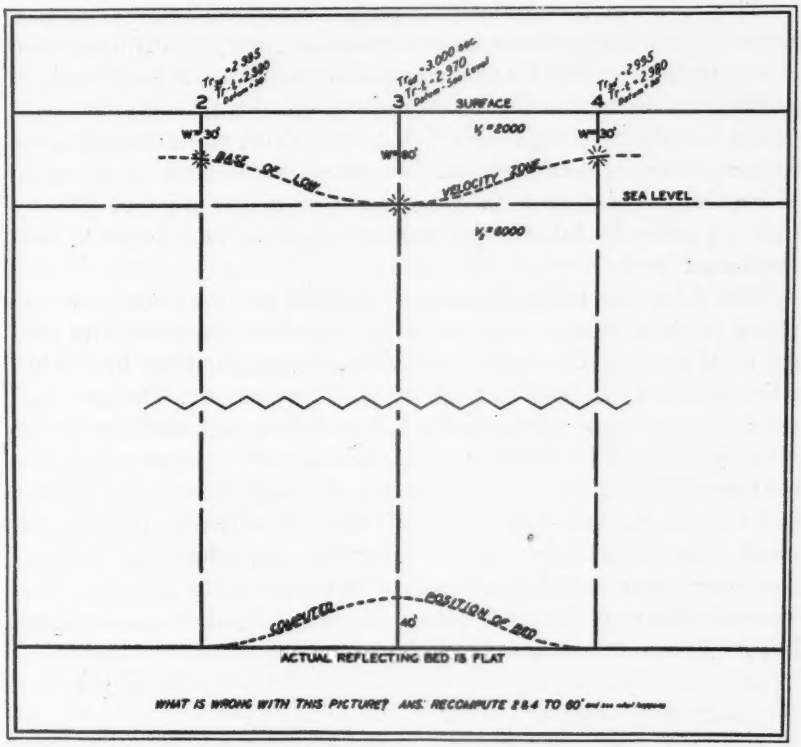


FIG. 2. What is wrong with this picture? *Answer:* Recompute 2 & 4 to 60 feet and see what happens.

be taken care of by subtracting the different datum levels from the depths. The answer, of course, rests in the fact that we are, in effect, applying the difference in datum reflection times on a time-depth curve, not at 6000 feet per second where the actual difference occurred, but at 14,000 feet per second (in this case) which is the interval velocity of the curve between the times of 2.970 and 2.980. It turns out that if the ratio of the unweathered velocity to the instantaneous

velocity of the time-depth curve at the observed reflection time is $\frac{1}{2}$, then the difference in subsurface datums will always be equal to but in the opposite direction to the difference in computation datum levels. In other words, if you compute the same data to two different datum levels, you raise or lower the depth of the beds a corresponding amount in the opposite direction.

This problem is extremely important, because it may happen gradually over a long distance rather than abruptly; in the former case it may result in a miss-tie to wells, and in the latter, it may result in showing a local high which is not present. For this reason, some companies now compute all results to a datum plane, either horizontal or inclined. The problem eventually becomes tied in with the question of whether the velocity surfaces are flat or inclined, but it is safe to say that in a generally flat area serious error can result from variable computational level.

One thing that brings this matter to mind is a job some years ago where we were able to map, on times, a shallow reflection with considerable success. The surface was generally flat, and the bed of low relief, but the depth of weathering was very erratic. The area had been core-holed extensively to the bed being mapped, and just for fun we tried to see if we could duplicate the core-hole picture on 10-foot contour intervals. The geologists, being of a suspicious nature, refused to let us see the core-hole map until after the seismograph map was made. The comparison was not favorable, but when the reflection times were recomputed to a constant datum level, the two maps were virtually identical. Naturally, the geologists claimed this was fudging, but it did show the source of our error.

III. VELOCITY ERRORS

The error just described brings to mind a boner pulled in New Mexico in the early days of reflection shooting. We were mapping a bed several thousand feet deep on correlation. Over a certain area the reflection showed short times, resulting in a closed high on the contour map. A well was drilled, finding nothing but a high head of salt water in what appeared to be a nice low. It turned out that a thick salt lens was present where our presumed high was mapped, and the increased velocity through the salt had made the reflection times to the deeper reflecting bed come in short over the area of the lens. In other words, our so-called high really represented an outline of the salt lens, while the deeper beds were actually lower at this point. If

we had been a little more critical of the configuration of the contours, we might have suspected the true nature of the apparent high, particularly since the occurrence of salt was common in this area.

In this connection one might wonder what sort of contour map would result if one were mapping a deep bed, and suddenly ran a traverse across some underground cavity such as the Carlsbad Caverns. It might be supposed that no reflections would be received in this exaggerated case, but there is some evidence to suggest that on a minor scale we have run across areas with small underground pockets or porous areas giving a subsurface weathering correction which has escaped detection, and resulted in mis-mapping of structure.

Another type of underground velocity condition which may cause a mis-mapping of the lower beds has recently come to notice. In certain parts of northern California, a basalt flow of variable thickness is buried a thousand feet or so below the surface, with true basement as much as 8000 feet deep. The objective horizons in the area, the Eocene and Cretaceous, occur below the basalt. The question arises as to whether the seismograph can map these lower zones, even if good reflections could be obtained. The basalt has a very high velocity and since its thickness is variable, it is debatable what value a map on lower beds might have. To complicate matters, it has been proved conclusively that multiple or echo reflections are obtained from the basalt, with this reflection repeating itself in a complex manner throughout the record.

This matter has come to light in another connection. In the Southern San Joaquin Valley, where the section is normal but very thick, there is a certain place where a nice structure exists in the upper beds. The seismograph also indicates a structure in the lower beds (at the objective horizon), but these dips look suspiciously like multiple reflections from the upper beds. The question now arises as to what extent seismograph work is subject to these influences, and suggests the possibility that some seimograph structures may have been found barren because the later impulses which have been mapped as deep reflections may actually be multiples or echoes of one sort or another, from unconformable upper beds. There is even the possibility that transverse waves have been picked and computed as deeper beds in some cases. These problems are a source of joy to the theoretical geophysicists, but are nothing but a headache to the operator who must decide whether to sink that $100,000 in a well or pay it in taxes.

Regional average velocity corrections are now an important part

of structure mapping in most parts of California. There are now about 150 wells surveyed for velocity in various parts of the State, and it can be argued with considerable success that closures have been both missed and erroneously introduced because of failure to consider the effect of lateral velocity gradient on the contours. It is certain that ties into wells not over 15 miles apart can be out as much as 2000 feet solely because of failure to consider regional velocity change, even when the cross-sections are computed from a velocity survey from either of the wells. This is an extreme case, but shows a source of error in our work.

Most geophysicists in the Gulf Coast feel that such significant lateral velocity gradients do not exist in this area, even though the geologic section is roughly the same as in California. However, it should be borne in mind that the density of well surveys in the Gulf Coast is not now sufficient to say for certain what local effect regional corrections will have on uncorrected contours. Furthermore, since it is the custom in this area to work local prospects as units without tying-in to widely separated wells, a great many potential miss-ties have never come to light. Perhaps Californians are looking for trouble unnecessarily.

IV. OTHER MISINTERPRETATIONS

Numerous oil fields have been missed in the past because insufficient study was given the results. Let me give a prime example of how this can happen in dip shooting. In Fig. 3 is shown a reproduction of a single cross-section. This was a guiding clue to an oil field, but was overlooked at the time because of the apparent poor quality of the data. Notice that the last two stations on the left hand side show a distinct flattening of dip, yet the reflections are mostly graded VVP. Additional work proved a reversal about opposite station 9 and resulted in a prolific oil field. Unfortunately, Company B found this field instead of Company A, although Company A shot this line one year earlier. It was felt at the time that the observed flattening was merely a result of the poor quality of data. A more trusting soul, unfamiliar with the limitations of the seismograph, believed this flattening, and proceeded to check it.

To give another example, examine the cross-section in Fig. 4. Would you have seen anything interesting? Well, this section is the clue to an oil field, when looked at with the proper amount of perspective. Notice that station 1 shows a decided flattening of dip. *Had*

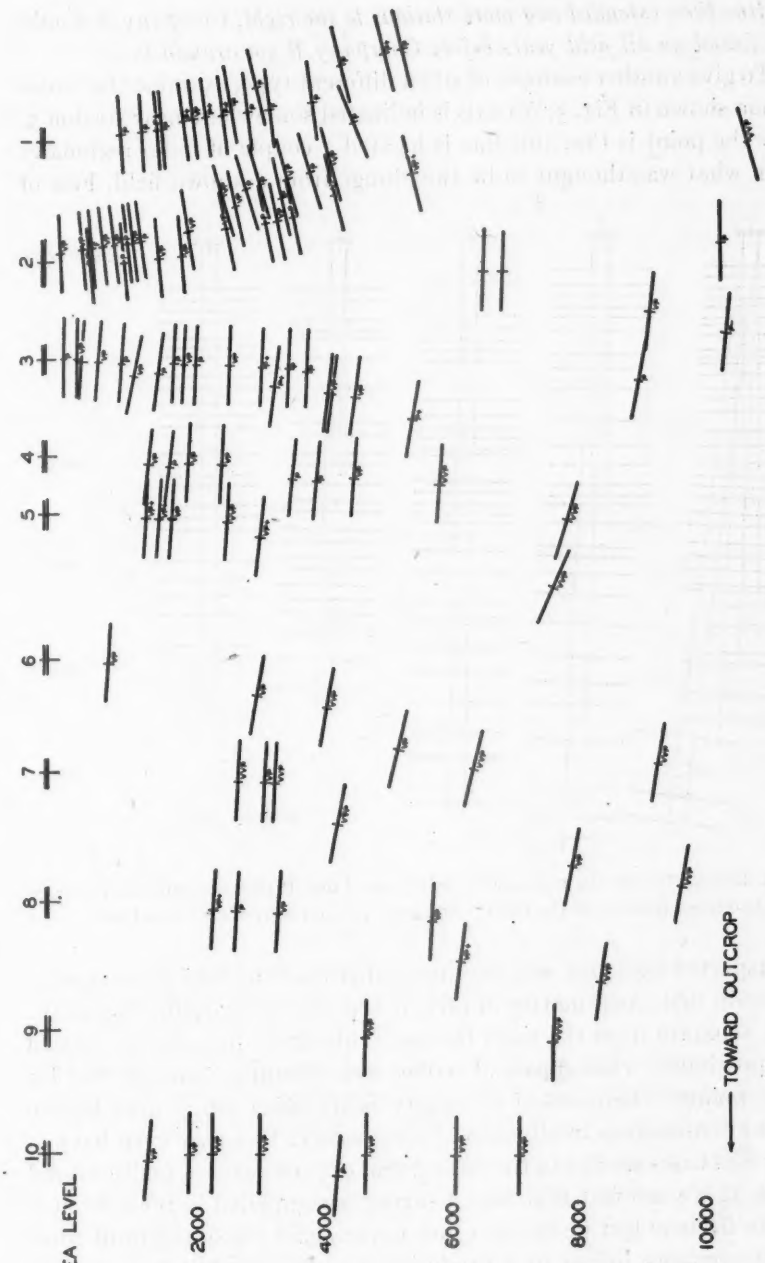


FIG. 3. Flattening shown on stations 9 and 10 was guiding clue to an oil field but was originally believed unimportant because of low quality of results.

this line been extended two more stations to the right, Company A would have found an oil field years before Company B got around to it.

To give another example of still a different type, examine the cross-section shown in Fig. 5. An axis is indicated somewhere near station 5. Now the point is that this line is located a couple of miles regionally down what was thought to be the plunge from a known field. Few of

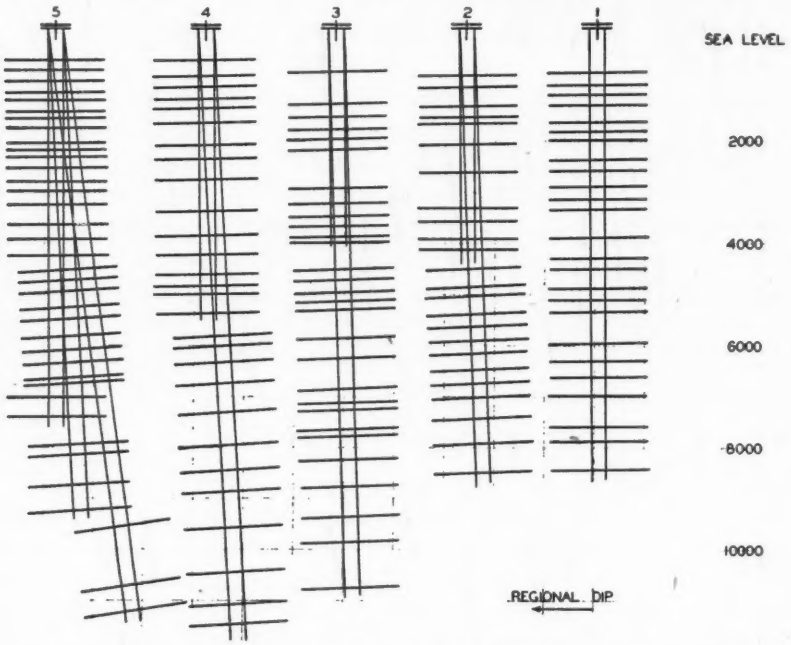


FIG. 4. Last station on the right shows flattening of dip. If this line had been extended two more stations to the right, Company A would have found an oil field.

us suspected that this was anything other than the final expression of the main fold. As a matter of fact, it is a clue to a prolific secondary field, separate from the main feature. This single line clearly showed this possibility when dips and strikes were computed and plotted for these points. The cases of secondary fields being found near known fields are numerous in all parts of the country. You may even have in your files cases similar to the ones given, or even cases of undiscovered fields. It is a sad fact that once a survey is completed in the field, it is apt to become lost in the files and never again consulted until some other company brings in a producer. Excuse me while I go consult my own files.

Another good way to miss a structure, particularly one of low relief, is to run lines at the wrong angle to the axis. Examine cross sections D and Q in Figs. 6 and 7. Cross-section D was shot N-S with stations 1000 feet apart. Cross-section Q was shot NE-SW, *normal to the usual axis of folding* in this general region, and shows a distinct anticline at the objective horizon of 10,000–15,000 feet. These two lines are on the same feature (Line *D* crosses line *Q* between station Q-14 and Q-15, while this point of crossing on line *D* is between D-12

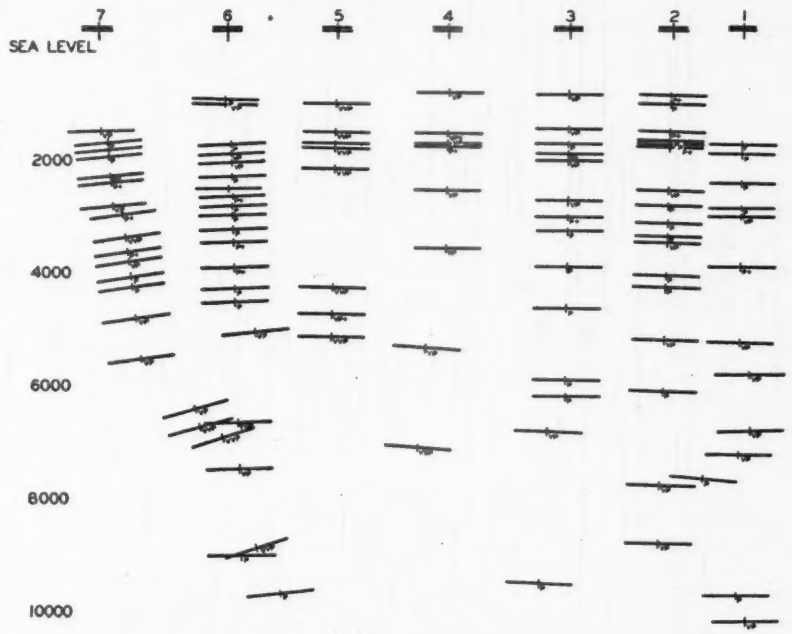


FIG. 5. Reversal shown on this line turned out to be a secondary oil field rather than final down-dip expression of the main fold.

and D-13). Of course section "D" does show a few flat or North dips, but some of these might be interpreted as erratics. This is particularly true of station 11 which apparently shows too much North dip throughout. The point is that running lines at unsuitable angles to the regional trend causes the maximum amount of distortion of the true cross-sectional picture.

In one well known case, Company A discovered a long low relief oil field trending Northwest-Southeast. Company B wanted to outline

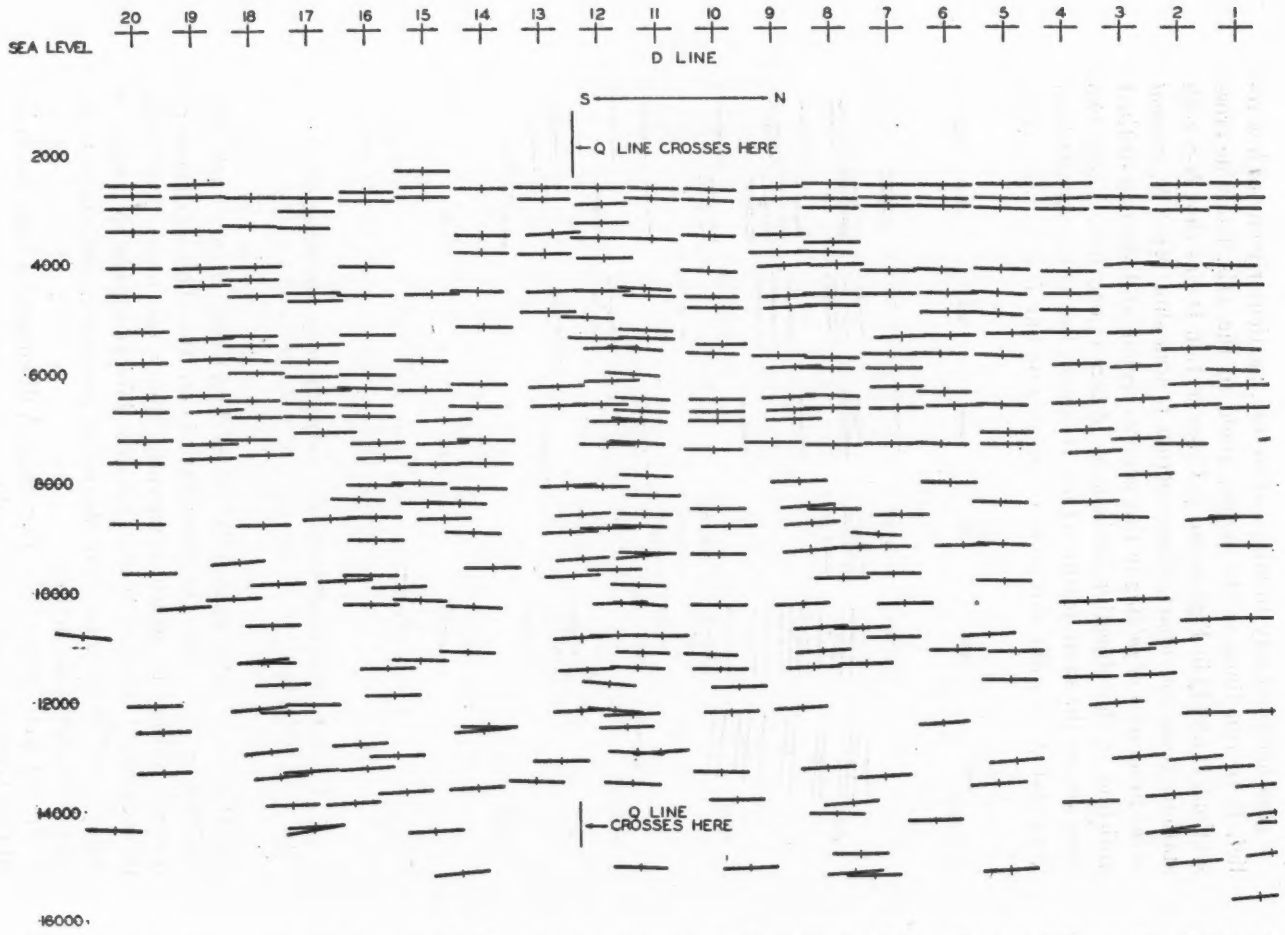
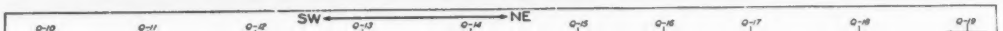


FIG. 6. Running lines at odd angles to regional dip may cause distortion of picture. Section *D* is on the same fold as section *Q* (Fig. 7), but at an oblique angle to the usual axis of folding for the area.



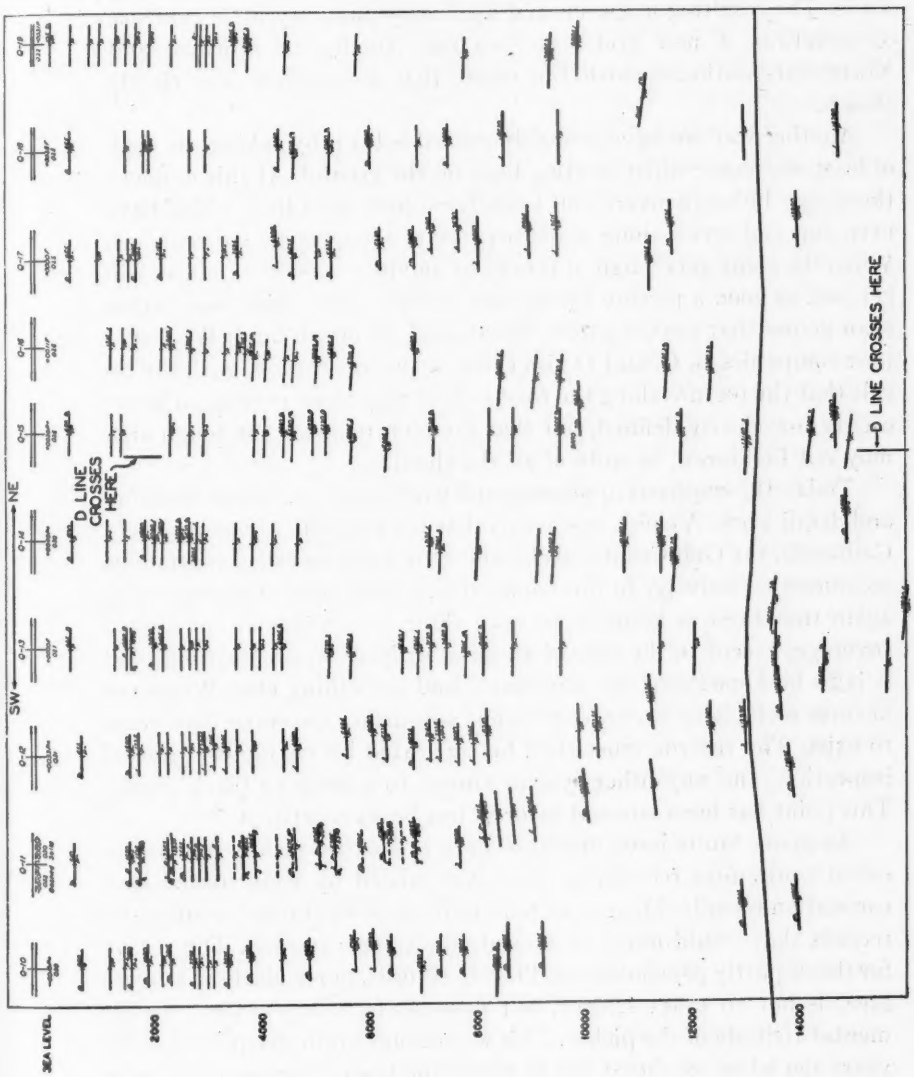


FIG. 7. Running lines at odd angles to regional dip may cause distortion of picture. This section is normal to the axis of folding. (Compare Fig. 6.)

but at an oblique angle to the usual axis of folding for the area.

the structure with the seismograph, and on receiving permission, proceeded to run a grid of North-South and East-West lines along roads. The resulting maps showed no closure and very little evidence of structure. A new grid was then run Northeast-Southwest and Northwest-Southeast, with the result that a structure was clearly shown.

Another way we have probably missed fields is by taking the path of least resistance when locating lines on the ground. At this moment there may be undiscovered oil fields lying just off of lines which have been run and rerun along roads because of topographic convenience. When the going gets tough, it is easy to convince ourselves that we will get just as good a picture by running along a convenient road rather than across that potato patch, wheat field, or marsh land. We forget that companies B, C, and D also came to this conclusion, with the result that the picture along the road (which may show nothing of interest) is now clearly defined, but that the picture *across* the tough area may not be known, in spite of all the shooting.

Today the emphasis in seismograph work is on continuous shooting and detail work. A check-up reveals that the majority of companies in California, the Gulf Coast and elsewhere are using so-called continuous technique exclusively. In this connection, it is important to emphasize again that there is actually no such thing as continuous subsurface coverage, except in the case of an uninterrupted monoclinal dip, and it is to be hoped that we sometimes find something else. Whenever flexures or faulting occur, continuous subsurface coverage may cease to exist. The records must then be correlated by character, interval inspection, and any other system known to science or black magic. This point has been stressed before,* but bears repetition.

As many faults have probably been missed by picking across so-called continuous records as were ever missed by wide spaced spot correlation records. Most of us tend to force picks through continuous records that would never be picked on separate records. The reason for this is partly psychological. Picking records, particularly in a tough area, is not an exact science, but depends to a large extent on the mental attitude of the picker. This was brought into sharp focus a few years ago when we shot a line in which the line and cross spread were

* Joseph L. Adler, *Geophysical Exploration for Stratigraphic Oil Traps*. GEOPHYSICS, Vol. VIII, No. 4, p. 345 (1943).

M. B. Widess, *Multiple Branches in Seismic Reflection-Time Surfaces*. GEOPHYSICS, Vol. VIII, No. 2, p. 93 (1943).

recorded simultaneously on separate halves of the same record. The party chief, when picking the records, subconsciously had in mind the usual type of record and tended to make his picks line up across the record, in spite of the fact that he knew that the two halves represented dips at right angles. The resulting cross-section was abnormal, and we then re-shot the line using the same line spread but having it appear across the record in the usual manner. The new section showed entirely different dips from the original. Theoretically, this is impossible, but in practice it can happen.

It is even suggested that one reason the seismograph has been slow to disclose stratigraphic traps may lie in the fact that most of us like to see move-outs line up on our records. We subconsciously pick dips which seem reasonable to the eye and which line up with picks at earlier and later times. We say to ourselves that that other possibility which shows discordant move-out is probably an erratic, and it therefore never appears on a map or cross-section. Reflections from fault planes can easily be overlooked in this same manner, because such reflections frequently appear on our records with radically discordant move-out, often crossing bands of energy from nearer or flatter beds. When one considers the fact that the record move-out on a surface spread of only 1000 feet must be about 150 milliseconds to represent a dip of 70°–75° from a surface only 2500 feet deep, it is easy to see how such reflections can be overlooked on the records. This is particularly true since reflections from such surfaces are frequently of apparent lower quality than other reflections on separate records, and since the normal position of the eyes, when picking, distinctly favors vertical move-out.

The psychological factor in picking records is not necessarily limited to cases of dip shooting. I well remember being caught in a spot correlation boner with "marked records." After drilling had disproved the correlation, a post-mortem revealed that the correlation, which looked excellent when the reflections were heavily marked with colored pencil on the record, looked even better when properly matched to fit wells. But it was necessary to consult *unmarked* records to see this better possibility. Once the records have been marked with heavy pencil or crayon, it is almost impossible to change the correlation, unless a fresh set of unmarked records of good quality is available. Marking the records obviously does not improve the correlation, but does create a psychological impression in favor of the marked correlation which the eye cannot readily discount.

Events of the last few years have convinced many of us that our ideas of how to correlate records must be revised and improved. It has now been proved, for example, that major faults may exist in lower beds without disturbing the upper beds. The question as to whether faults may exist in upper beds without affecting the lower zones has not been settled, but exists as a possibility. Thus, the old correlation criterion of time-interval between reflections will no longer hold in many cases. We must become accustomed to anticipating this possibility. Automatic volume controls have, to a certain extent, robbed us of amplitude criteria for character correlations, and the increased number of reflections introduced by better amplifiers and filters greatly complicates as well as aids correlation. Things have now reached the point where the quiet spots on the records may be the clues to the proper correlations rather than the reflections themselves.

One thing is certain. Correlations will never be made unless someone has the time to study the records. The answers are usually on the records, but too often they never appear on maps or cross-sections, because the party chief—in these days of voluminous bookkeeping and exasperating personnel problems—never has time to really study the records. The reflections are picked once, a map is hastily made, and the data goes in the files to be lost and forgotten until some other company finds a field where we had that irregularity.

This seems a strange procedure indeed when you remember the $10,000 a month that it costs to get the information, and the present great need for oil. Perhaps an oil field is buried somewhere in *your* files. How about reviewing some of that old "dope" and spending a little time in really studying the records? And if time permits after writing stuff like this, I will do the same.

ANALYSIS FOR HYDROCARBONS IN THE PRESENCE OF NITROUS OXIDE*

MONROE W. KRIEGEL†

ABSTRACT

The technique for the analysis of soil air for small quantities of hydrocarbons is reviewed. Various methods of expressing results and the basis for the calculation of each are given. Field data on expansion ratios are presented to show that there exists in the soil air a gas, other than the saturated hydrocarbons, which is not removed by the screening agents and is retained in the condensation trap. The reasons for believing that this gas is nitrous oxide are given, together with plausible sources of this gas in the soil air. Laboratory data are presented on the analysis of pure hydrocarbons in the presence and in the absence of this gas. Calculations made by each of the methods show that when results are based on after-burning readings, a true measure of the hydrocarbon content is evolved, regardless of the presence of nitrous oxide.

I. SCOPE OF THIS PRESENTATION

In the analysis of soil air for hydrocarbons the supposition had long been made in this laboratory that simple reagent traps, such as ascarite and phosphorus pentoxide or concentrated potassium hydroxide and concentrated sulfuric acid, would screen out all interfering gases and allow an analysis of the material condensed at the temperature of liquid nitrogen with the confidence that an accurate measure could be made of both the hydrocarbon concentration and the average number of carbon atoms in the molecule. In this paper results of extensive field work on the free or unadsorbed gas in the soil air will show that at least one interfering gas does exist. The attempts to identify this gas will be given, together with laboratory data to show how its presence affects the hydrocarbon analysis and methods of calculation.

II. ANALYSIS OF AIR FOR SMALL QUANTITIES OF HYDROCARBONS

In order to follow the line of reasoning in this paper, it is necessary that the analysis procedure used here for hydrocarbons in the air be clearly understood. The early stages in the development of an analysis unit for this purpose were described by Sokolov.[1] Pictures and brief

* Presented at the fourteenth annual meeting, Dallas, Texas, March 1944.

† Carter Oil Company, Tulsa, Oklahoma.

[1] Sokolov, V. A., "Gas Surveying," published in Russian in 1936, translated by I. M. Gubkin in 1939.

descriptions of this method of analysis have been presented by Horvitz,[2] Rosaire,[3] and Stormont.[4] Patents on the use of this and similar equipment have been issued to Horvitz,[5] who has presented orally[6] details of the analysis procedure. Probably the best published description of the arrangement and operation of analysis equipment for the detection and quantitative measurement of the small concentrations of hydrocarbons is given by Heiland.[7] The procedure followed by this laboratory is similar to, but not exactly the same as, that described in the above references. Hence, to avoid confusion, it might be well to describe in detail the analysis of soil air for hydrocarbons as it is done here.

The principle is essentially that of screening out interfering gases such as carbon dioxide and water vapor, with proper reagent traps; condensing and separating ethane and heavier hydrocarbons from methane, oxygen, nitrogen, and other non-condensible gases by the use of low temperature and vacuum; burning the condensed gases in an excess of oxygen; and measuring the amount of carbon dioxide formed. In Fig. 1 is shown a line diagram of the essential parts of a single unit of the analysis apparatus. A sample pipette containing soil air with its small content of hydrocarbons is attached as shown. With the stopcock to the pipette closed, the entire assembly, with the exception of the oxygen supply bulb, is pumped down to the vapor pressure of mercury by the mercury diffusion pump. Stopcock 2 is then closed and stopcock 1 is opened. The condensation trap is immersed in liquid nitrogen, then stopcock 2 is slowly opened and the air and hydrocarbons in the sample pipette are allowed to pass through the dry reagents, into the condensation trap, and the non-condensibles through the diffusion pump. When the pressure in the system has been reduced to a few millimeters, mercury valve 3 at the left of the condensation trap is shut and the pressure in the system to the right of this valve is reduced to the vapor pressure of mercury. In the con-

[2] Horvitz, Leo, GEOPHYSICS, 4, 210–225 (1939).

[3] Rosaire, E. E., *The Handbook of Geochemical Prospecting* (1939).

[4] Stormont, D. H., *Oil and Gas Journal*, 52, September 14, 1939.

[5] Horvitz, Leo, U. S. Patent 2,198,619, issued April 30, 1940, and U. S. Patent 2,261,764, issued November 4, 1941.

[6] Horvitz, Leo, Presented before Petroleum Division of the American Chemical Society in St. Louis, April, 1941, and before the Society of Exploration Geophysicists in Houston, April, 1941.

[7] Heiland, C. A., "Geophysical Exploration," New York, Prentice-Hall, Inc. (1940).

densation trap will be retained all of the paraffin hydrocarbons except methane. Mercury valve 5 is then closed, the burning trap is immersed in liquid nitrogen, and the condensation trap is warmed to −80°C by replacing the liquid nitrogen bath with one containing dry ice dissolved in acetone. This causes the hydrocarbons in the light fraction, or ethane, propane, butane, pentane, and hexane, to vaporize

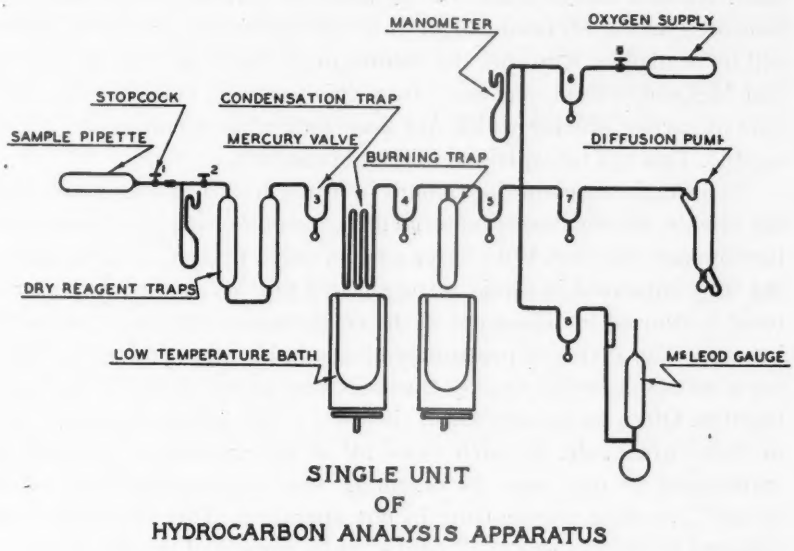


FIG. 1. Schematic diagram of a single unit of the hydrocarbon analysis apparatus used in this work.

and to recondense in the burning trap. To get a measure of the volume of light hydrocarbons before combustion, the liquid nitrogen bath on the burning trap is replaced by a dry-ice bath, and with valves 5 and 8 open, and 4, 6, and 7 closed, light hydrocarbons are allowed to vaporize into the McLeod gauge. After noting the resulting pressure, which is called the before-burning pressure (P_{BB}), the hydrocarbons are recondensed in the burning trap by immersing it again in liquid nitrogen.

With valve 4 still shut and with valves 7 and 8 closed, 6 is opened and oxygen is slowly admitted through stopcock 9 until a pressure of about 2 mm., as noted on the manometer, has been added to the burning trap. Valve 5 is closed and the trap and its contents are warmed to

room temperature. A high frequency discharge is then passed through the gas, causing the combustion of the hydrocarbons. After combustion of the sample the burning trap is again immersed in liquid nitrogen and the excess oxygen pumped out by means of the diffusion pump. Then, with valves 4, 6, and 7 closed, and valves 5 and 8 open, the liquid nitrogen bath on the burning trap is replaced by a dry-ice bath. At this temperature, the pressure of carbon dioxide may be measured on the McLeod gauge, while the vapor pressure of the water will be negligible. Knowing the volume of the burning trap, manifold, and McLeod system, one may, from this pressure, calculate the volume of carbon dioxide which has been formed on combustion of the sample. This will be explained in the next section.

In order to measure the amount of heavy hydrocarbons present in the sample, the remaining material in the condensation trap is warmed to room temperature. With valve 4 open, valve 5 closed, and the burning trap immersed in liquid nitrogen, this portion of the sample material is allowed to diffuse out of the condensation trap into the burning trap. The taking of pressure readings and combustion of the sample is accomplished in exactly the same way as was done for the light fraction. Often measurements of the total hydrocarbon content above methane are made. In such cases all of the condensed material is transferred in one step, by warming the condensation trap from $-196°C$ to room temperature in one operation. This procedure was followed in the analysis of all field samples presented in this paper.

III. METHODS OF CALCULATION

The general equation for the combustion of hydrocarbons is as follows:

$$C_nH_{2n+2} + \frac{3n+1}{2} O_2 = nCO_2 + (n+1)H_2O. \qquad (1)$$

As explained in the preceding section, measurements in a system of known volume of the pressure before-burning (P_{BB}) before the addition of oxygen gave a means of determining the absolute amount of the pure hydrocarbon present, while the after-burning pressure (P_{AB}) when measured after the non-condensible gases had been pumped off and with the burning trap at $-80°C$, such that water vapor would have a negligible vapor pressure, gave a measure of the amount of CO_2 formed. Throughout this paper the terms "before-burning pressure," (P_{BB}), and "after-burning pressure," (P_{AB}), will

refer to measurements made as described above and in the preceding section. The percentage of hydrocarbons in the gas would be expressed by:

$$\frac{P_{BB} \cdot V_s}{10^3 \cdot 760 \cdot V_p} \times 100 = \% \text{ hydrocarbons} \qquad (2)$$

where V_s = volume of the system in which the pressure measurement is made, V_p = volume of the sample in the pipette, and P_{BB} is the before-burning pressure in microns. Since the percentages are often very small, it is usually more desirable to express the results in terms of parts per million by volume, as follows:

$$\frac{P_{BB} \cdot V_s}{10^3 \cdot 760 \cdot V_p} \times 10^6 = \text{P.P.M. hydrocarbons.} \qquad (3)$$

Substituting k for $V_s \cdot 10^6 / 10^3 \cdot 760 \cdot V_p$ for a system of constant size and for a constant sample volume, Eq. 3 becomes

$$P_{BB} \cdot k = \text{P.P.M. hydrocarbons.} \qquad (3')$$

Results may also be calculated on the basis of the after-burning readings, as follows:

$$\frac{P_{AB}}{n} \cdot k = \text{P.P.M. hydrocarbons} \qquad (4)$$

where n = number of carbon atoms in the hydrocarbon molecule, and P_{AB} = after-burning pressure in microns. Since the light hydrocarbons as separated consist of ethane through hexane, it is convenient in practice to express the results on the basis of an average hydrocarbon, such as butane, in which equation (4) becomes:

$$\frac{P_{AB}}{4} \cdot k = \text{P.P.M. light hydrocarbons.} \qquad (4')$$

The heavy hydrocarbons may be expressed as octane, or:

$$\frac{P_{AB}}{8} \cdot k = \text{P.P.M. heavy hydrocarbons.} \qquad (4'')$$

There is always the possibility that a small amount of CO_2 will pass the ascarite and be retained in the condensation trap. Since the volume of CO_2 does not change when exposed to the discharge in an excess of oxygen, the effect of CO_2 in the condensation trap would be to in-

crease both P_{BB} and P_{AB} by a constant amount. Hence, to compensate for the possible presence of this material, calculations may be made as follows:

$$\frac{(P_{AB} - P_{BB})}{(n - 1)} \cdot k = \text{P.P.M. hydrocarbon} \qquad (5)$$

or, if results are still expressed as butane—

$$\frac{(P_{AB} - P_{BB})}{3} \cdot k = \text{P.P.M. light hydrocarbon.} \qquad (5')$$

A consideration of the above equations shows that for pure hydrocarbons, the parts per million of hydrocarbons may be calculated by equations 3, 4, or 5. Equation (3) is based on the premise that the material in the condensation trap is hydrocarbon only. Equation (4) has as its basis that the products of combustion will give a true measure of the hydrocarbon concentration, while equation (5) is based on the supposition that any material in the condensation trap other than hydrocarbon will either be non-reactive or will form materials having the same volume as the initial materials under the conditions of after-burning measurement. In the absence at this point of evidence of other interfering gases and in view of the possibility of getting CO_2 in the condensation trap, equation (5) would seem to be the most desirable for general use in calculating the results of measurements made on soil air. Data will be presented later in this paper to make such a conclusion untenable.

The term, "expansion ratio," in this paper will be used to express the ratio of after-burning to before-burning readings, or P_{AB}/P_{BB}, in which both readings are made as pointed out in the procedure. On this basis, the expansion ratio of pure ethane would be 2, propane would be 3, or would be n in the general equation (1) $C_nH_{2n+2} = nCO_2$. Since methane is not retained in the condensation trap, it is apparent that the minimum expansion ratio possible on combustion of pure hydrocarbons would be 2. Even if the ascarite traps were to fail to remove the CO_2, the expansion ratio of a mixture of CO_2 and hydrocarbons would approach 1 as a limit.

IV. FIELD DATA ON EXPANSION RATIOS

In connection with other geochemical studies, samples of soil air were taken from a number of areas in Oklahoma and other states. Sample locations were not less than .1 or more than .5 miles apart.

The procedure for the collection of the sample material was to dig a six-foot hole, insert a small pipe to within a few inches of the bottom, pack off the upper part of the hole, and connect evacuated pipettes to the top of the pipe. After withdrawing sufficient soil air to cleanse the sampling line of surface air, samples were retained for analysis.

In Table I are shown the expansion ratios obtained on analysis of soil air samples from areas in Oklahoma, Kansas, Arkansas, and Louisiana. In Fig. 2 are shown the distribution curves for the data in

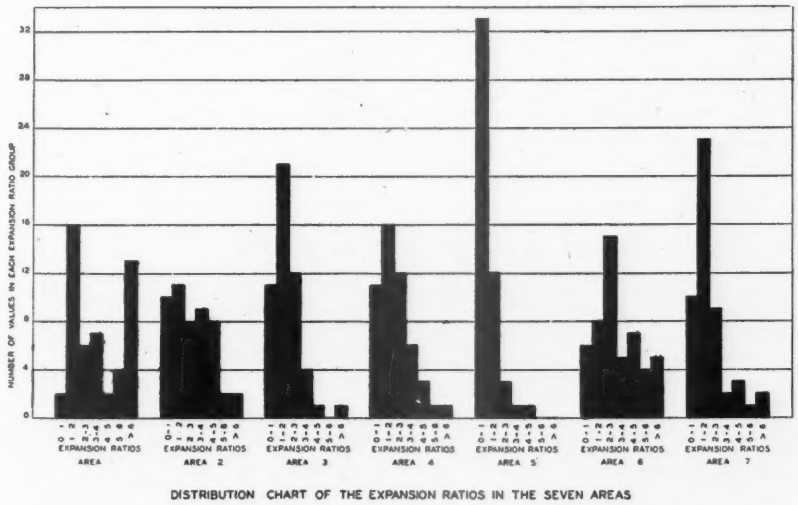


FIG. 2. Schematic presentation of the expansion ratios. In each area the number of values lying between 0–1, 1–2, etc. is plotted as ordinates.

each of the seven areas. To illustrate how these were prepared, consider area 2. Here ten of the values have expansion ratios of greater than 0 but less than 1.00, eleven are greater than 1.01 but less than 2.00, eight between 2.01 and 3.00, etc. Thus the various vertical lines represent the number of expansion ratios lying between arbitrarily selected limits. In order to show the variation between locations, the data on areas 5 and 6 are shown graphically in Figs. 3 and 4 respectively. In both of these two areas samples were taken along profiles on .2 mile spacing with continuous lines in Fig. 3 along locations 1 through 6, 7 through 27, and 28 through 50, and in Fig. 4 along 1 through 19 and 20 through 50.

TABLE I. EXPANSION RATIO VALUES

Location Number	*Area Number*						
	1	2	3	4	5	6	7
1	5.6	1.52	.48	1.32	.96	3.0	.245
2	1.3	.86	5.0	.65	2.0	4.1	.75
3	3.54	5.0	1.63	1.54	.65	1.01	1.7
4	8.8	2.3	2.5	1.73	.11	1.70	.95
5	4.33	1.72	.17	1.46	.10	3.95	2.0
6	6.3	3.14	2.72	1.47	.079	.66	1.06
7	11.1	2.91	1.46	2.44	1.05	2.5	.74
8	1.45	2.22	2.2	1.40	.25	1.9	2.14
9	8.0	1.31	1.86	4.52	1.68	.24	2.65
10	.31	.75	2.15	2.61	2.9	1.1	17.8
11	.6	.47	1.2	2.66	.20	1.24	4.77
12	3.5	2.12	2.7	3.27	.30	2.28	4.3
13	1.45	.76	1.33	3.4	.30	1.64	1.41
14	10.3	2.67	1.38	3.48	.22	.54	1.15
15	1.4	4.23	1.63	5.28	.44	4.5	1.7
16	1.9	2.77	1.07	4.55	.25	.085	1.6
17	3.0	3.95	1.4	2.55	2.59	6.95	1.9
18	4.0	.17	.18	2.48	.34	.17	10.2
19	2.56	4.57	1.47	1.93	.14	.35	1.5
20	1.56	1.07	1.92	2.79	.77	1.96	1.13
21	1.44	.93	.14	.78	1.78	5.3	1.48
22	1.26	1.07	2.25	.43	.34	3.4	2.68
23	2.0	2.43	2.14	1.16	1.98	1.28	1.73
24	5.8	.33	.96	2.10	.76	2.5	2.2
25	1.14	8.35	2.3	3.78	.69	6.9	1.78
26	3.0	3.6	1.0	1.6	1.06	2.8	1.1
27	3.45	4.7	1.41	3.03	2.47	3.4	5.6
28	2.5	3.47	1.5	1.41	1.51	4.3	2.12
29	5.6	1.18	1.47	4.0	3.20	4.65	.68
30	6.45	3.27	2.88	2.3	.30	2.6	1.46
31	7.5	.7	3.0	2.1	4.8	3.0	4.0
32	4.1	2.55	1.14	.11	.40	2.4	2.3
33	6.7	.55	2.5	1.35	1.56	3.1	1.9
34	10.1	.29	3.3	.73	.034	2.86	.29
35	9.8	3.43	3.28	.10	1.87	2.5	1.6
36	3.25	4.21	2.9	2.67	1.7	5.33	1.6
37	3.2	1.75	1.8	1.43	1.41	2.5	2.04
38	1.8	3.30	9.3	2.17	.36	2.4	.64
39	3.3	7.0	3.96	1.45	.18	4.85	2.69
40	1.44	4.27	1.25	21.5	.009	3.93	1.22
41	1.3	3.01	1.75	4.4	.17	5.76	.28
42	2.0	1.24	.728	.29	.36	6.73	3.08
43	1.97	5.7	1.54	.66	.27	2.6	2.28
44	5.33	4.1	.98	1.04	.712	4.2	1.30
45	7.7	1.66	.16	2.29	.47	7.55	1.15
46	7.25	5.1	.055	.044	.29	5.0	4.55
47	2.7	1.1	1.48	.15	1.14	6.1	.52
48	3.0	4.5	1.16	1.67	.138	2.26	.75
49	1.5	3.86	3.48	.14	.48	4.45	1.33
50	9.4	1.02	1.00	1.5	.745	2.3	1.05

TABLE II. SUMMARY OF EXPANSION RATIO DATA

Area Number	Average Expansion Ratios			Per Cent of Total Below 2
	All Values	Below 2	Above 2	
1	3.95	1.362	5.15	32
2	2.67	.975	3.89	42
3	1.903	1.148	3.25	64
4	.236	1.016	3.92	54
5	.955	.677	2.99	88
6	3.17	.992	3.97	28
7	2.31	1.18	4.30	64
Average	2.474	1.500	3.924	53.1

It will be noted in both the figures and in the individual expansion ratios that there is no uniformity in the ratios in any single area. It will also be noted that the expansion ratios of many of the samples are less than 2, and that a considerable number are less than 1.

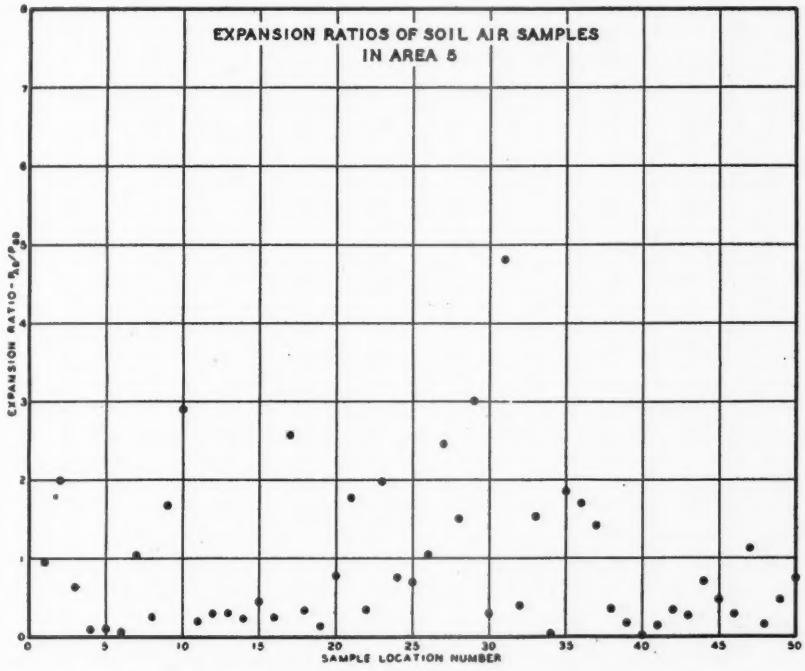


FIG. 3. Showing the expansion ratios obtained in a typical series of samples. The sample locations are .2 mile apart.

In Table II are shown the averages of the individual values in Table I. Here are presented the average expansion ratios of all the samples in each area, the average of the ratios above 2, and the average of those below 2. Included in the table is the percentage the number of stations showing values below 2 is of the total 50 stations in each area. The averages show that in the seven areas studied, 53.1 per cent, or from 28 to 88 per cent, of the samples of soil air contained a gas other

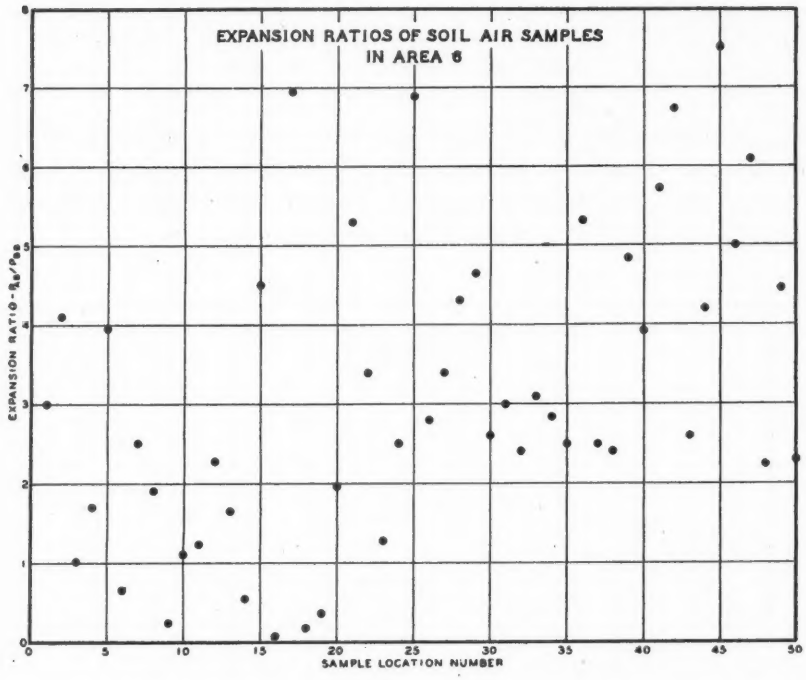


FIG. 4. Showing the expansion ratios obtained in a series of samples taken in another area. Most of the values are along lines with locations .2 mile apart.

than pure hydrocarbons. This is a minimum value, since it does not take into account those samples in which the expansion ratio may have been reduced somewhat but not enough to bring its value below 2. Some of the values are extremely low, for example number 18 in area 3, number 46 in area 4, number 16 in area 6, and many others.

It is apparent from these data that the gas causing the reduction in expansion ratio is present in non-uniform concentrations in many areas. It will be remembered that the hydrocarbon content of the

samples, which is not discussed in this article, will also influence the expansion ratio. However, in general it was observed that the variation in hydrocarbon content among samples in any one area was not sufficient to account for the large variation in expansion ratios. Since no areal correction could be applied, it was important that the gas be identified in order that provisions might be made for its removal ahead of the condensation trap or for a method of calculation in which its presence would not influence the results.

V. IDENTIFICATION OF THE CONDENSED GAS

The gas causing the decrease in expansion ratio must be one which has certain definite properties. It must not react with ascarite or phosphorus pentoxide, must have a vapor pressure at low temperature similar to the light hydrocarbons (examination of many high field samples showed it to lie in the light fraction) which have a boiling point range of $-110°C$ to $+35°C$, and must on combustion in excess oxygen form a material which is either not condensed at $-196°C$ or is not volatile at $-80°C$. The latter point is important to note carefully. If the product of combustion is non-condensible at the temperature of liquid nitrogen, it will be pumped out with the excess oxygen. On the other hand, if the reaction product has a boiling point in the same range as water, it will not be volatile at $-80°C$, and hence will not be measured with the CO_2 in the regular after-burning reading.

According to Scott[8] a mixture of gases unadsorbed by most of the common reagents might contain H_2, CH_4, C_2H_2, C_2H_4, N_2O, N_2, COS, and the noble gases. Hence it might be well to consider these initial possibilities. For convenience in following these discussions the boiling points[9] at 760 mm. of all of the gases entering the considerations are given in Table III. Within the paraffin hydrocarbon series the normal boiling points give a relative measure of the vapor pressure characteristics at $-80°C$ and $-196°C$. This analogy is not strictly true when applied to other gases, but is used as the basis of the division into the two groups in Table III. The ones which have too high boiling points at 760 mm., or too high vapor pressure to be retained in the trap at a temperature of $-196°C$ and a total pressure equal to the va-

[8] Scott, W. W., "Standard Methods of Chemical Analysis," New York, D. Van Nostrand Co. (1939).

[9] Hodgman, C. C., and Holmes, H. N., "Handbook of Chemistry and Physics," Twenty-sixth edition, Cleveland, Ohio, The Chemical Rubber Publishing Company (1942).

por pressure of mercury, are H_2, N_2, and CH_4, and all of the noble gases except Xe and Rn. Since C_2H_2 and C_2H_4 would readily burn to CO_2 and cause an expansion in volume, they may be eliminated. Since xenon and radon are non-reactive, they would not satisfy the requirements in that the volume would remain constant. Carbon oxysulfide

TABLE III. BOILING POINTS OF GASES AT ONE ATMOSPHERE

Methane, or Non-Condensible Fraction			*Light Hydrocarbon, Volatile at −80°C, Fraction*		
Name	*Formula*	*B.P. ° C 760 mm.*	*Name*	*Formula*	*B.P. °C at 760 mm.*
Methane	CH_4	−161.6	Ethane	C_2H_6	−88.5
Oxygen	O_2	−183	Propane	C_3H_8	−42.5
Nitrogen	N_2	−196	Butane	C_4H_{10}	−0.5
Carbon Monoxide	CO	−190	Pentane	C_5H_{12}	+36.1
Hydrogen	H_2	−252.8	Hexane	C_6H_{14}	+68.8
Nitric Oxide	NO	−151.8	Carbon Dioxide	CO_2	−78.5
Argon	A	−185.7	Nitrous Oxide	N_2O	−89.5
Neon	Ne	−245.9	Carbon Oxy-Sulfide	COS	−50.2
Helium	He	−268.9	Xenon	Xe	−107.1
Krypton	Kr	−152.9	Radon	Rn	−61.8

has the proper boiling point, but according to Dennis[10] this material will decompose with heat in the presence of oxygen according to the following equation:

$$COS + \tfrac{3}{2}O_2 = CO_2 + SO_2.$$

Since both of these products of combustion are condensed at −196°C and volatilized at −80°C, they will appear in the after-burning reading and cause a net expansion ratio of 2. Thus, all except nitrous oxide may be eliminated as possibilities.

The boiling point of nitrous oxide is such as would place it in the light hydrocarbon fraction. Joshi[11] has made a comprehensive series of investigations into the dissociation of nitrous oxide in the silent discharge at pressures above 10 cm. mercury, finding the dissociation to be according to the following reactions:

$$2N_2O = 2N_2 + O_2$$

$$2N_2O = 2NO + N_2$$

$$2NO = N_2 + O_2.$$

[10] Dennis, L. M., and Nichols, M. L., "Gas Anlaysis," New York, The Macmillan Company (1929).

[11] Joshi, S. S., *Trans. Fara. Soc. 23*, 227–38 (1927); *25*, 137–43 (1929).

Stewardson[12] found the total pressure after combustion to be 1.5 times the initial pressure, indicating that decomposition is complete, i.e. equilibrium is reached only when all of the nitrous oxide is decomposed, there being no appreciable reverse reaction.

Although these reactions were not carried out in an excess of oxygen, it seemed reasonable to assume—subject to laboratory investigation—that the reaction products would be the same. An examination of Table II will show that none of the reaction products are condensible at the temperature of liquid nitrogen. Thus, nitrous oxide seems to satisfy the requirements for the type gas found in the soil air.

The presence of nitrous oxide in the soil is not surprising when it is remembered that the element nitrogen in the form of ammonium salts, nitrites, or nitrates is present in fertile soils. One method[13] of preparation of pure nitrous oxide is according to the equation:

$$NH_4NO_3 = N_2O + 2H_2O.$$

It is probable that the slow decomposition of commercial fertilizers might account for some of the nitrous oxide in farming areas. In connection with the studies of decomposition of vegetation under aerobic conditions it has been shown by this laboratory that a gas having properties similar to nitrous oxide forms a large portion of the condensed fraction.

VI. LABORATORY STUDIES ON NITROUS OXIDE AND HYDROCARBONS

Having found that nitrous oxide has such properties as would favor a behavior in the presence of hydrocarbons similar to that of the unknown gas, and having established that the presence of this gas in the soil air is not unusual, it remained to test the effect of this gas on the analysis of samples of pure hydrocarbons. In Table IV are presented the results of analysis of pure propane and pentane alone and in the presence of excesses of nitrous oxide. In separate five-gallon jugs were prepared samples of propane, pentane, and nitrous oxide in the concentration ranges often encountered in geochemical soil air samples. The initial concentration of hydrocarbon in the jug was determined in each case by withdrawing and analyzing a 335 cc. sample. Calculations were made on the basis of the before-burning pressure,

[12] Stewardson, E. A., *Trans. Fara. Soc. 30*, 1018–1027 (1934).

[13] Partington, J. R., "A Text-Book of Inorganic Chemistry," London, Macmillan and Company (1939).

the after-burning pressure, and the difference between the before- and after-burning pressures, or according to Eqs. 3, 5, and 4, respectively. Then, an analysis was made of a sample from the same jug mixed with a sample from one of the jugs containing nitrous oxide. This was done by passing in one 335 cc. sample of air containing the hydrocarbon, condensing and transferring to the burning trap, making a before-burning reading, passing in a 335 cc. sample of air and nitrous oxide,

TABLE IV. RESULTS OF ANALYSIS FOR PROPANE AND PENTANE IN THE PRESENCE OF NITROUS OXIDE

Material	k	P_{BB}	P_{AB}	Expansion Ratio	kP_{BB}	$\frac{k(P_{AB}-P_{BB})}{n-1}$	$\frac{kP_{AB}}{n}$
	$\frac{V_s-10^6}{760 \cdot V_p \cdot 10^3}$	Microns	Microns	$\frac{P_{AB}}{P_{BB}}$	P.P.M.	P.P.M.	P.P.M.
Propane No. 1 Alone	.2345	20.1	56.7	2.82	47.1	42.9	44.3
Propane Fraction	.2345	19.2			45.0		
Nitrous Oxide Fraction		22.5					
Propane+Nitrous Oxide		41.7	55.1	1.33	97.8	11.5	43.1
Propane No. 1 Alone	.2370	20.2	57.4	2.84	47.8	44.1	45.3
Propane Fraction	.2370	19.2			45.5		
Nitrous Oxide Fraction		26.2					
Propane+Nitrous Oxide		45.4	56.8	1.25	107.5	13.5	44.8
Propane No. 2 Alone	.2345	11.2	32.4	2.89	26.3	24.9	25.3
Propane Fraction	.2342	10.8			25.3		
Nitrous Oxide Fraction		12.5					
Propane+Nitrous Oxide		23.3	33.7	1.45	59.3	12.2	26.3
Pentane No. 1 Alone	.2345	8.12	45.9	5.65	19.05	22.1	21.5
Pentane Fraction	.2345	8.33			19.5		
Nitrous Oxide Fraction		22.00					
Pentane+Nitrous Oxide		30.33	46.6	1.54	71.2	9.55	21.9
Pentane No. 1 Alone	.2370	8.83	49.3	5.58	20.9	23.9	23.3
Pentane Fraction	.2370	9.04			21.4		
Nitrous Oxide Fraction		23.60					
Pentane+Nitrous Oxide		32.64	49.4	1.51	77.4	9.93	23.4
Nitrous Oxide+Air	.2342	12.9	4.20	.325	30.2	− 5.1*	1.97*
Nitrous Oxide+Air	.2345	24.5	3.68	.150	57.5	−12.2*	1.73*
Nitrous Oxide+Air	.2370	24.9	3.85	.155	58.9	−12.5*	1.82*

* Calculated as Pentane

condensing and transferring, making a before-burning reading of the combined materials, and then adding oxygen and burning and measuring the products of combustion in the usual manner. To illustrate, consider the first unit in the table, which is propane number one and nitrous oxide. The initial concentration of propane in the jug, as determined on a sample withdrawn for such analysis, was found to be 47.1, 42.9, or 44.3, as calculated from equations 3, 5, and 4, respectively. Those results are all within the limit of experimental accuracy. A second propane sample from the same container showed a concentra-

tion of 45 P.P.M., as calculated on the basis of the before-burning reading, or using Eq. 3. The nitrous oxide from a 335 cc. sample taken out of one of the containers of that gas brought the initial pressure up to a value of 41.7 microns. Considering only the total before- and after-burning pressures, calculations were made as if this were a regular field sample in which all of the condensed gas was hydrocarbon. On this basis the values of the hydrocarbon concentration were found to be 97.8, 11.5, and 43.1 P.P.M. by the three methods of calculation.

In the last three experiments shown in Table IV nitrous oxide was added to air containing a very small amount of combustible material. The results indicate abnormally high values for the apparent hydrocarbon content when calculated on the before-burning basis, negative values when calculated on the difference basis, and normal values when calculations are based on the after-burning reading only.

VII. CALCULATIONS OF HYDROCARBON CONTENT IN THE PRESENCE OF NITROUS OXIDE

It is now apparent that from both a theoretical and experimental basis, no method of calculation of hydrocarbon content can be used if it is based on either the before-burning or on the difference between before- and after-burning basis when nitrous oxide is present in the sample material. Thus, the equation for calculation in either the presence or absence of nitrous oxide is:

$$\frac{P_{AB} \cdot V_s \cdot 10^6}{n \cdot 10^3 \cdot 760 \cdot V_p} = \text{P.P.M. by volume of hydrocarbons in air}$$

where

P_{AB} = After-burning pressure in microns
n = Number of carbon atoms in the molecule
V_s = Volume of the system in cc.
V_p = Volume of the sample in the pipette in cc.

VIII. SUMMARY

1. The details of the procedure for the analysis of air for small quantities of hydrocarbons have been reviewed. The various methods of calculation and means of expressing results, under the assumption that there were no interfering gases, have been given.

2. Field data on expansion ratios have shown that there is often

present in soil air a gas which interferes with certain of the measurements and methods of calculation.

3. A study of the literature and of properties of the disturbing gas indicates that it is nitrous oxide. Plausible reasons for expecting to find this gas in the soil air are given.

4. Laboratory data on combustion of pure propane and pentane with nitrous oxide indicate that the method of analysis and one method of calculation is satisfactory for hydrocarbons in the presence or absence of nitrous oxide.

QUANTITATIVE INTERPRETATION OF MAGNETIC AND GRAVITATIONAL ANOMALIES*

ERVAND G. KOGBETLIANTZ†

ABSTRACT

A new interpretation method for gravitational and magnetic anomalies based on the use of average values (integrals) of suitably chosen functions of the observed quantity is discussed and illustrated by application to the particular case of a symmetric anticline. The quantitative interpretation yields the position of the apex, the slope of the sides, the thickness, the depth of the base of the anticline, as well as the density contrast for the gravitational case and the magnitude and direction of the magnetization vector for the magnetic case.

INTRODUCTION

Geophysical surveying became necessary only when geological prospecting had mapped almost all outcrops and discovered all mineral deposits and oil fields sufficiently shallow to be found by purely geological methods. Only the coming exhaustion of such deposits discoverable by the study of the tectonic structure of the uppermost part of the earth's crust compelled the prospectors to change their methods, to study and apply geophysical methods in prospecting.

During its first twenty years, 1920–1940, geophysical surveying was directed mostly towards the study of relatively simple and easy cases. Excessively deep or excessively small deposits and gentle tectonic structures which create in general small anomalies were neglected, and exploration geophysicists looked for and studied clearly defined anomalies which correspond to shallow deposits and to big, well-defined tectonic structures. On the other hand, the regions characterized by complex anomalies resulting from superposition of many simple anomalies were declared as rather unsuitable for geophysical prospecting for the too simple reason that the interpretation of the maps of complex anomalies was considered almost impossible.

This situation was not serious as long as the simple anomalies of fairly large magnitude were not yet exhausted. But now geophysicists are forced to deal with more difficult cases, and they have to interpret maps of small as well as of complex anomalies. The usual interpretation methods, which are based on the systematic use of individual

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critical values (extrema, zeros, inflection-points, etc.), and of their distances, helpful as they are in easy cases, are useless and cannot be successfully applied in the general case. In fact, they have been elaborated on the essential assumption that the map under consideration is that of a simple anomaly created by a single geologic phenomenon, i.e., an isolated mineral body or tectonic structure. But a general method for the resolution of a complex anomaly map into partial maps of component simple anomalies, whose superposition forms the observed and mapped anomaly, is lacking. Furthermore, the usual interpretation of a simple anomaly with the aid of critical values and distances is based on the tacit assumption that these values and distances reflect exclusively the action of the unknown structure or ore-body whose study is the ultimate purpose of the interpretation. This assumption is true approximately for an anomaly of large magnitude but it becomes questionable if the anomaly is of average magnitude and is completely wrong for small anomalies.

New interpretation methods are necessary and they *must* be introduced into practice if geophysical prospecting by gravimetric and magnetic methods is to be usefully applied in the future. These new methods are based, like the old ones, on the theory of potential, and they solve the two fundamental problems: (A) resolution of a complex anomaly map into maps of simple component anomalies, and (B) quantitative interpretation of small anomalies.

In this paper we study the problem (B) in the case of an axial anomaly created by an anticline whose axis is horizontal. All results given here are based on the assumption that the cause of the anomaly is an anticline. If this fact in a concrete case cannot be proved by geology or by existing borings, it can be deduced from the study of the anomaly map itself by one of the existing general methods especially devised for this purpose by the author and which solve the problem (A). Consequently, the interpretation rules formulated in this paper are to be considered as a method of detailed quantitative interpretation and they must be applied only after the first interpretation has shown that the anomaly corresponds to an anticline.

In the two-dimensional case we are considering here there is a classical Poisson's relation between the two components Z (vertical), X (horizontal) of the magnetic anomaly, and the gravity gradient $U_{xz}=G$ and curvature $U_{xx}=K$, ($U_{xy}=U_{yy}=U_{yz}=0$):

$$f\cdot\sigma\cdot(X+iZ) = I\cdot e^{-i\psi}\cdot(K+iG),$$

where f, σ, I, ψ denote the gravitational constant, density contrast, intensity of magnetization, and angle of inclination of the magnetization vector, respectively. By means of this relation we transform the interpretation rules formulated in this paper for the case of G- and K-maps into interpretation rules for Z- and X-maps of a magnetic anomaly created by an anticline. All considerations developed below with respect to gravity anomalies hold equally for magnetic anomalies.

1. *Punctual Anomaly*

Let us first study the obstacles which naturally lead to an erroneous interpretation of a given map if the magnitude of the anomaly is not very large. We do not have in mind the well known theoretical fact of nonuniqueness of solution of the interpretation problem. We are not concerned here with this purely theoretical objection. The map itself, picturing the behavior of any one among gravitational quantities: Dg (variation of the gravity acceleration g), U_{zz}, U_{yz}, U_{Δ}, $2U_{xy}$ (second derivatives of the potential U), gradient G, curvature K, total anomaly $A=(G^2+K^2)^{\frac{1}{2}}$, is supposed to be generally correct and to have had applied to it all the usual reductions. A map for Dg, for instance, must be corrected for latitude, free-air, Bouguer and terrain corrections. Such a map is plotted on the basis of measurements made at isolated station-points. All usual corrections having been made, each individual value of the observed quantity obtained at a station is the combined effect of three gravitational actions: 1) regional anomaly, 2) anomaly caused by the tectonic structure or the ore-body the study of which is the aim of the interpretation and 3) anomaly generated by local irregularities of mass distribution in the immediate vicinity of and under the point of measurement. This local anomaly —we propose to call it a "punctual anomaly"—is in general very small and affects only a small area around the point-station. It is this punctual anomaly which is responsible for perceptible variations in the station-value of the observed quantity which occur for small displacements of the apparatus used through two or three yards. In fact, the apparati used now in gravimetric and magnetic surveys are extremely sensitive and we cannot safely neglect the existence of punctual anomalies.

A map can and must be corrected for the regional anomaly, but there is no correction at all for the punctual anomaly affecting each observed value: ***it cannot be evaluated.*** After the correction for regional anomaly is made two circumstances are possible. If the magnitude of

the anomaly studied is large the punctual anomalies are negligible and the map can be interpreted by the usual methods. The positive results achieved by the old interpretation methods which use the individual values are explained in this way. But if the magnitude of the anomaly is small the punctual anomalies not only modify the extremal values and all the ratios, but they also displace these critical values, altering all the distances used in the usual interpretation. This important fact explains the lack of success in dealing with maps of small anomalies.

If we wish to eliminate the errors of interpretation caused by punctual anomalies, there is only one possible way to do it. Considered altogether, the punctual anomalies in the region mapped have a random distribution: they oscillate about zero and are independent one from another. Consequently, they must undergo an almost total compensation if we form the average value of some function of observed and mapped quantity, provided that the regional anomaly has already been removed. Using all the map at a time, combining all observed values in an integral, we eliminate the harmful influence of punctual anomalies. For any map in general the average values express much better the gravitational action of the phenomenon under study than do the individual values and their distances. Formulas based on the individual values hold only in very rare and exceptional cases of big structures such as the salt domes of Texas, Kursk, and the Kirunawaara iron ores or the Great Rhodesian Dyke.

In this paper we introduce a new interpretation method in which the interpretation rules use exclusively the average values and, in particular, moment-functions and moments of the observed quantity and of its square. The method has been applied in practice by the author in France and in Iran. The case of an anticline is chosen here only for the sake of brevity; the author has developed his method for the most general cases of complex anomaly maps obtained as a result of a magnetic or gravimetric survey.

2. *Formulation of the Interpretation Problem*

Taking the vertical directed downward as the Z-axis, let us consider a cylindrical body of normal cross-section S, having a density contrast σ and stretching parallel to the Y-axis, the horizontal plane XOY being that of the map (Fig. 1). The section S is in the plane XOZ and the potential U of the body does not depend on the coordinate y:

$U = U(x, z)$. Computing the difference $U(x, z) - U(x_0, z_0)$, where (x_0, y_0, z_0) is any fixed point, we get

$$U(x, z) = U(x_0, z_0) + f\sigma \iint_A dS \cdot \int_{-\infty}^{\infty} [R_0^{-1} - R^{-1}] d\eta \qquad (1)$$

with

$$R^2 = (x - \xi)^2 + \eta^2 + (z - \zeta)^2, \; R_0^2 = (x_0 - \xi)^2 + \eta^2 + (z_0 - \zeta)^2,$$
$$f = 66.7 \times 10^{-9} \text{ cgs}$$

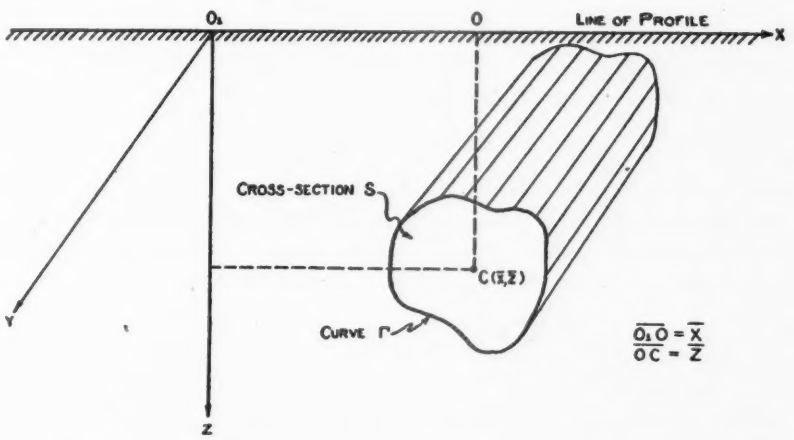

FIG. 1. Illustrating the quantities used in the formulation of the interpretation problem. An infinite cylinder lies with its generatrices parallel to the Y axis. $C(\bar{x}, \bar{z})$, the centroid of the cross-section S of the cylinder, lies at a horizontal distance $\bar{x}$ from the origin O_1 and at a depth $\bar{z}$ below the surface. Γ is the bounding curve of the cross-section.

being the gravitational constant, and ξ, η, ζ being the coordinates of a point of the cylinder.

Here

$$\int_{-\infty}^{\infty} [R_0^{-1} - R^{-1}] d\eta = 2 \log (r/r_0)$$

if

$$r^2 = (x - \xi)^2 + (z - \zeta)^2 \quad \text{and} \quad r_0^2 = (x_0 - \xi)^2 + (z_0 - \zeta)^2.$$

Denoting the constant $2f\sigma$ by k, we get from (1):

$$U(x, z) = k \iint_A \log r \cdot dS + \text{constant}, \qquad (2)$$

where the double integration is extended over the area A of the cross-section S.

The partial derivatives U_x, $Dg = U_z$ of the potential U considered at the surface, $z = 0$, have at the point $(x, 0, 0)$ the values

$$U_x = k \iint_A r_x' \cdot dS/r = k \iint_A (x - \xi) dS/r^2,$$

$$U_z = k \iint_A r_z' \cdot dS/r = - k \iint_A \zeta \cdot dS/r^2,$$

and combining them in a complex expression $U_x - iU_z$ we get the important formula

$$U_x - iDg = - k \iint_A (x - \rho)^{-1} dS = k \int_\Gamma \log (x - \rho) d\zeta \quad (3)$$

where $\rho = \xi + i\zeta$ is the radius-vector of the point (ξ, ζ) which describes the area A of the cross-section S or the curve Γ, the boundary of S.

Differentiating the relation (3) with respect to x, we have also an expression involving the gravity gradient G and the curvature K,

$$K - iG = k \iint_A (x - \rho)^{-2} dS = k \int_\Gamma (x - \rho)^{-1} d\zeta. \quad (4)$$

Using the binomial expansion, we find for large $|x|$:

$$U_x - iDg = - (k/x) \sum_0^\infty x^{-n} \iint_A \rho^n dS =$$
$$- (kA/x)[1 + (\bar{x} + i\bar{z})/x + \cdots]$$

$$K - iG = (k/x^2) \sum_0^\infty (n + 1) x^{-n} \iint_A \rho^n dS$$
$$= kA x^{-2}[1 + 2(\bar{x} + i\bar{z})/x + \cdots],$$

where $\bar{x}$ and $\bar{z}$ are coordinates of the center of gravity C of the area A. We see that, for large $|x|$, U_x, Dg, G and K for any form of the section S are of the orders $|x|^{-1}$, x^{-2}, $|x|^{-3}$ and x^{-2} respectively:

$$U_x \sim kA/x;\ Dg \sim kAz/x^2;\ G \sim -2kAz/x^3;\ K \sim kA x^{-2}(1 + 2\bar{x}/x). \quad (5)$$

Before applying the general formulas (3) and (4) to an anticline we have to choose some simple geometrical form of its cross-section S well adapted to express adequately its gravitational action and at the

same time amenable to mathematical computation. For this purpose we consider a symmetric anticline as a single infinite disturbing layer of constant density contrast σ and of original thickness T (see Fig. 2). For $|x| \geqq l$ this layer remains horizontal, but in the interval $-l<x<l=\overline{EC}$ its (originally also horizontal) part, of length $2l_0$, $(l_0>l)$, compressed by tangential forces, forms an anticline of cross-

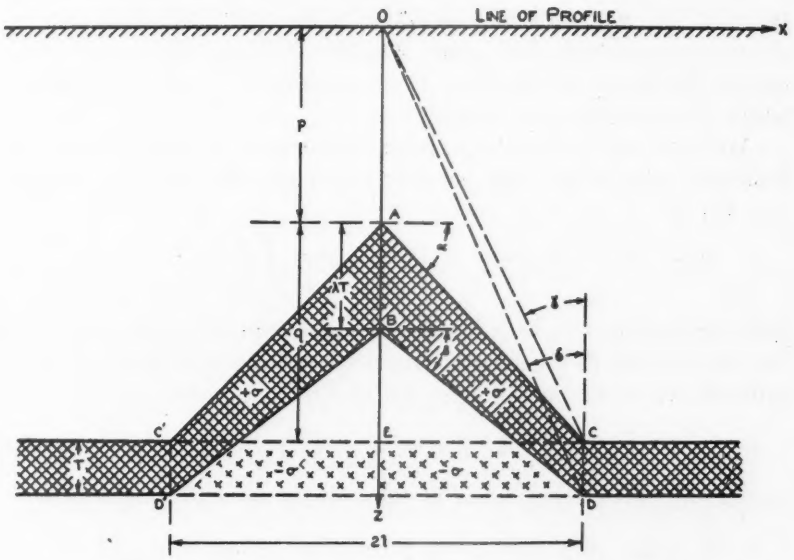

FIG. 2. Illustrating the quantities required for application of the method of interpretation to an idealized representation of a symmetric anticline.

section S limited by the segments of straight lines $\overline{D'C'}$, $\overline{C'A}$, $\overline{AC}$, $\overline{CD}$, $\overline{DB}$, $\overline{BD'}$. The excess-mass $2(l_0-l)\cdot T\cdot\sigma$ and the maximum thickness $\lambda T=\overline{AB}(\lambda>1)$ are related and $(1+\lambda)\cdot l=2l_0$. We characterize the cross-section by the parameters α, β, γ, δ where α, β, $90°-\gamma$, $90°-\delta$ are the angles of the lines $\overline{AC}$, $\overline{BD}$, $\overline{OC}$, $\overline{OD}$ with the horizontal axis $\overline{OX}$ (the line of profile). Denoting the depth $\overline{OA}$ of the apex A by p and the distance $\overline{AE}$ (displacement of the apex upward) by q, we have

$$l=q\cot\alpha=[q-(\lambda-1)T]\cot\beta=(p+q)\tan\gamma=(p+q+T)\tan\delta. \quad (6)$$

Therefore, l, q, λ and T can be expressed as functions of α, β, γ, δ and in all there are seven parameters k, (i.e., σ), α, β, γ, δ, $\bar{x}$, p. The last

two are coordinates of the apex of the anticline with respect to an arbitrary origin O_1 on the profile. The gravitational anomaly of an anticline is due not only to the excess-mass of its section $C'ACDBD'C'$ of area A_1, but also to the suppression of the mass $2 \cdot l \cdot \sigma \cdot T$ of the horizontal section $C'CDD'$ in $-l \leq x \leq l$. Therefore in what follows we ascribe to this cross-section $C'CDD'$ the negative density-contrast $-\sigma$, denoting its area by A_2. The final purpose of the quantitative interpretation in the case under consideration is the numerical determination of seven parameters which means location of the anticline and knowledge of its density contrast σ, slope α, thickness T and λT, height q, width $2l$ and depth p of its apex.

We turn now to the interpretation problem of the magnetic survey. Poisson's relation between magnetic and gravity elements, written (see Eq. 4)

$$X - iZ = Ie^{i\psi} \cdot (K - iG)/f\sigma = 2Ie^{i\psi} \iint_A (x - \rho)^{-2} dS \qquad (7)$$

indicates that in this case, instead of σ, the angle of inclination ψ and the magnitude I of the magnetization vector are also unknowns of the problem. We have the following list of eight parameters

$$I, \psi, \bar{x}, p, \alpha, \beta, \gamma, \delta, \qquad (8)$$

whose numerical values must be determined by the interpretation.

3. *First Moments and the Position of the Points O and C*

First we must find the value of $\bar{x}$, the distance $\overline{O_1O}$ which fixes the position of the unknown point O on our profile, the origin O_1 being chosen arbitrarily. This can be done with the aid of the following general result:

For any cylindrical body the center of gravity of the infinite area, bounded by the line of profile, which is taken as the X-axis, and the experimental curve $Dg = Dg(x)$, is on the same vertical as the center of gravity C of the cross-section S of the cylindrical body. Therefore the ratio M_1/M_0 of the first two moments of the function $Dg(x)$ is equal to $\bar{x}$.

$$\bar{x} = M_1/M_0. \qquad (9)$$

Let $\rho = \xi + i\zeta$ be a fixed complex number whose imaginary part ζ is positive and x a complex variable. Integrating $(\rho - x)^{-1} \cdot dx$ in the plane of this variable along a contour consisting of the interval $(-L, L)$ on

the x-axis and of the upper half of the circumference of a circle with radius L and center at the origin, we get

$$\int_{-\infty}^{\infty}(\rho - x)^{-1}\cdot dx = \lim_{L=\infty}\int_{-L}^{L}(\rho - x)^{-1}\cdot dx = -i\pi.$$

Observing that $kA = k\iint_A dS$, we deduce from (3) the relation

$$x(U_x + kA/x) - ixDg = k\int\int_A \rho(\rho - x)^{-1}\cdot dS. \qquad (10)$$

Integrating (3) and (10) with respect to x from $-\infty$ to $+\infty$, we have:

$$\int_{-\infty}^{\infty}(U_x - iDg)dx = k\int\int_A dS\cdot\int_{-\infty}^{\infty}(\rho - x)^{-1}\cdot dx = -i\pi kA$$

$$\int_{-\infty}^{\infty}[x(U_x - iDg) + kA]dx = k\int\int_A \rho dS\int_{-\infty}^{\infty}(\rho - x)^{-1}\cdot dx = \pi kA(\bar{z} - i\bar{x}).$$

The imaginary parts of these equations give the expressions for the first two moments M_0, M_1*

$$M_0 = \int_{-\infty}^{\infty} Dg\cdot dx = \pi kA, \qquad M_1 = \int_{-\infty}^{\infty} xDg\cdot dx = \pi kA\,\bar{x} \qquad (11)$$

thus proving Eq. 9. If the measurements give only the curve of the gradient G (survey with the aid of a gradiometer), so that $d(Dg) = Gdx$ is known, then, integrating by parts, we have, using for the m-th moment of the gradient the notation H_m:

$$H_0 = \int_{-\infty}^{\infty} Gdx = 0, \qquad H_1 = \int_{-\infty}^{\infty} xGdx = -\pi kA = -M_0,$$

$$H_2 = \int_{-\infty}^{\infty} x^2G\cdot dx = -2\pi kA\,\bar{x} = -2M_1$$

whence the value of $\bar{x}$

$$\bar{x} = H_2/2H_1. \qquad (12)$$

A torsion balance gives two curves: $G = G(x)$ and $K = K(x)$. It is interesting to note that for the curvature K the first two moments vanish and its third moment is related to the depth $\bar{z}$ of the center of

* The integral M_1 is defined as limit for $L\to\infty$ of an integral over the interval $(-L, L)$.

gravity C. Eq. 5 proves that the third moment of K can be defined only as the moment of the difference $(K-kAx^{-2})$. This difference can be considered as a known quantity since the product $x^2(K-kAx^{-2})$, whose integral is the value of the third moment, is equal to x^2K+H_1/π, H_1 being equal to $-\pi kA$. To compute the third moment L_2 of $K(x)$ we first integrate Eq. 10 with respect to x over the interval $(-\infty, \infty)$ and take the real parts which gives

$$\int_{-\infty}^{\infty} x(U_z + kA/x)dx = -\pi k \text{ Real } \left\{ i \cdot \iint_A \rho dS \right\} = \pi kA\bar{z}.$$

Next integrating this integral by parts we transform it into L_2, whence

$$L_2 = \int_{-\infty}^{\infty} [x^2K + H_1/\pi]dx = -2\pi kA\bar{z} = 2H_1\bar{z} \tag{13}$$

and the formula for the depth $\bar{z}$ of the center C is

$$\bar{z} = L_2/2H_1. \tag{14}$$

In general a torsion balance survey gives much more information than a gravimeter or a gradiometer survey and the result of Eq. 14 is a good illustration of this.

Let us now study the case of a magnetic survey. From Eq. 7 we have

$$\begin{aligned} kX &= 2I(K\cos\psi + G\sin\psi) \\ kZ &= 2I(G\cos\psi - K\sin\psi). \end{aligned} \tag{15}$$

Using Eq. 5, we have for large $|x|$:

$$X \sim 2IA\cos\psi \cdot x^{-2} \quad \text{and} \quad Z \sim -2IA\sin\psi \cdot x^{-2}. \tag{16}$$

Multiplying (15) by dx and $x \cdot dx$ and integrating over the interval $(-\infty, \infty)$ we express the first two moments X_0, X_1 of X and Z_0, Z_1 of Z in terms of moments $L_0=L_1=0$ of K and $H_0=0$, $H_1=-\pi kA$ of G. Therefore $X_0=Z_0=0$ and

$$\begin{aligned} \int_{-\infty}^{\infty} x \cdot X \cdot dx &= X_1 = -2\pi IA\sin\psi; \\ \int_{-\infty}^{\infty} x \cdot Z \cdot dx &= Z_1 = -2\pi IA\cos\psi. \end{aligned} \tag{17}$$

To determine the third moments X_2, Z_2 we form and integrate the differences

$$
\begin{aligned}
x^2X + Z_1/\pi &= x^2\cdot(X - 2IA\cos\psi/x^2)\\
&= 2k^{-1}\cdot Ix^2[(K - kA/x^2)\cdot\cos\psi + G\sin\psi]\\
x^2Z - X_1/\pi &= x^2\cdot(Z + 2IA\sin\psi/x^2)\\
&= 2k^{-1}\cdot Ix^2[G\cdot\cos\psi - (K - kA/x^2)\sin\psi]
\end{aligned}
$$

with the result:

$$
\begin{aligned}
X_2 &= \int_{-\infty}^{\infty}[x^2X + Z_1/\pi]dx = 2I(L_2\cos\psi + H_2\sin\psi)/k\\
Z_2 &= \int_{-\infty}^{\infty}[x^2Z - X_1/\pi]dx = 2I(H_2\cos\psi - L_2\sin\psi)/k.
\end{aligned}
\tag{18}
$$

Substituting in Eq. 18 the values from Eqs. 12 and 13 of H_2 and L_2 we find

$$
\begin{aligned}
X_2 &= -4\pi IA(\bar{x}\cdot\sin\psi + \bar{z}\cdot\cos\psi)\\
Z_2 &= -4\pi IA(\bar{x}\cdot\cos\psi - \bar{z}\cdot\sin\psi).
\end{aligned}
\tag{19}
$$

The four moments X_1, X_2, Z_1, Z_2 can be used to find four among eight parameters listed in (8). These four parameters are $\bar{x}$, $\bar{z}$, ψ and IA. Their expressions are:

$$
\begin{aligned}
2\bar{x} &= (X_1^2 + Z_1^2)^{-1}\cdot(X_1X_2 + Z_1Z_2);\\
2\bar{z} &= (X_1^2 + Z_1^2)^{-1}\cdot(Z_1X_2 - X_1Z_2)\\
\psi &= \arctan(X_1/Z_1) \text{ and } 2\pi IA = (X_1^2 + Z_1^2)^{1/2}.
\end{aligned}
\tag{20}
$$

Consequently, these four moments X_1, X_2, Z_1, Z_2 not only fix the position of the point C but also give the inclination ψ of the magnetization and the value of the product IA, which will give I if A is found from the interpretation process to be illustrated.

4. *Reduction to a Finite Interval of Integration (Profile)*

The theoretical formulas deduced in Section 3 cannot be applied as they are stated for the simple reason that the experimental curve of the observed quantity is known only in a finite interval $(-L, L)$, if we denote the length of the profile by $2L$ and choose the origin O_1 at its mid-point. Integrating the experimental curve and the curves derived from it with the aid of a planimeter over the finite interval $(-L, L)$ instead of $(-\infty, \infty)$, we obtain numbers which can be considered as first approximate values of the moments, if the profile is sufficiently long and $\bar{z}/L$ is very small. This is always the case if the

map is a good one since then the profile was prolonged sufficiently to get negligibly small values of the observed quantity at both ends. Taking into consideration the contribution of intervals $(-\infty, -L)$, (L, ∞) we compute the reduction coefficients with the aid of which the numerical values of the moments can be calculated, integrating over the finite interval $(-L, L)$ only.

Taking the origin of coordinates (x', z') at the center of gravity C of the cross-section S and the axes parallel to x- and z-axes, we introduce the characteristic constants c_{mq} defined by

$$A \cdot c_{mq} = \iint_A x'^m \cdot z'^q \cdot dS.$$

Thus, $c_{00}=1$, $c_{10}=c_{01}=0$. They depend on the form and orientation of S. The radius vector ρ in Eqs. 3, 4 and 7 is now $\rho=\bar{x}+x'+i(\bar{z}+z')$ and, expanding $(1-\rho/x)^{-1}$ and $(1-\rho/x)^{-2}$ in series and denoting the constants $\iint_A \rho^n dS$ by B_n, we have

$$U_x - iDg = -k\sum_0^\infty B_n \cdot x^{-n-1}, \qquad K - iG = k\sum_0^\infty (n+1)B_n \cdot x^{-n-2}.$$

The coefficients B_n can be expressed in terms of $\bar{x}$, $\bar{z}$, A, c_{mq}. For instance $B_0=A$, $B_1=A(\bar{x}+i\bar{z})$, $B_2=A[(\bar{x}+i\bar{z})^2+c_{20}-c_{02}+2ic_{11}]$. For large $|x|$ we have the following approximate expressions

$$Dg \sim kA\bar{z} \cdot x^{-2} \cdot [1+2C_1 \cdot x^{-1}+C_2 x^{-2}] \tag{21}$$

$$G \sim -2kA\bar{z} \cdot x^{-3} \cdot [1+3C_1 \cdot x^{-1}+2C_2 x^{-2}] \tag{22}$$

$$K \sim kA \cdot x^{-2} \cdot [1+2\bar{x} \cdot x^{-1}+C_3 \cdot x^{-2}] \tag{23}$$

$$X \sim 2IAx^{-2} \cdot \cos\psi \cdot [1+2(\bar{x}-\bar{z} \cdot \tan\psi)x^{-1}+(C_3-C_4 \cdot \tan\psi)x^{-2}] \tag{24}$$

$$Z \sim 2IAx^{-2} \cdot \sin\psi \cdot [1+2(\bar{x}+\bar{z} \cdot \cot\psi)x^{-1}+(C_3+C_4 \cdot \cot\psi)x^{-2}], \tag{25}$$

where $C_1=\bar{x}+c_{11}/\bar{z}$, $C_2=3\bar{x}^2-\bar{z}^2+3(c_{20}-c_{02})+(3c_{21}+6c_{11}\bar{x}-c_{03})/\bar{z}$, $C_3=3(\bar{x}^2-\bar{z}^2+c_{20}-c_{02})$, $C_4=6\bar{z} \cdot C_1$. Using these expressions, we can evaluate with great precision the contributions of two infinite intervals $(-\infty, -L)$, (L, ∞) to each among the nine moments M_0, M_1, H_1, H_2, L_2, X_1, X_2, Z_1, Z_2 used in Eqs. 9, 12, 14, and 20. Denoting their first approximate values, obtained by integrating in the finite interval $(-L, L)$, by the same letters with horizontal bars and neglecting the terms of relative orders $(\bar{z}/L)^2$ and $(\bar{x}/L)^2$, we have—(26): $M_0=\overline{M}_0 \cdot (1+2\bar{z}/\pi \cdot L)$; $H_1=\overline{H}_1 \cdot (1+4\bar{z}/\pi L)$; $M_1=\overline{M}_1 \cdot [1+4(\bar{z}+c_{11}/\bar{z})/\pi L]$; $H_2=\overline{H}_2 \cdot [1+6(\bar{z}+c_{11}/\bar{z})/\pi L]$; $X_1=\overline{X}_1 \cdot [1+4(\bar{z}-\bar{x} \cot \psi)/\pi L]$;

$Z_1=\overline{Z}_1\cdot[1+4(\bar{z}+\bar{x}\cdot\tan\psi)/\pi L]$. Therefore the rules expressed by Eqs. 9 and 12 become,

$$\bar{x} = [1 + 2(\bar{z} + 2c_{11}/\bar{z})/\pi L]\cdot\overline{M}_1/\overline{M}_0$$

and
$$\bar{x} = [1 + 2(\bar{z} + 3c_{11}/\bar{z})/\pi L]\cdot\overline{H}_2/2\overline{H}_1. \quad (27)$$

We can improve the first approximate values of $\bar{x}_1$ obtained by using in Eqs. 9 and 12, instead of M_0, M_1, H_1, H_2 the numbers $\overline{M}_0$, $\overline{M}_1$, $\overline{H}_1$, $\overline{H}_2$, only after having achieved the first step of the successive approximation and obtained first approximate values for all parameters, since they are needed for the computation of the reduction factors in (26). Thus, beginning with $\bar{x}_1$, we calculate the first values for all other parameters (see Sections 5 and 6 below) and we improve the first value $\bar{x}_1$ with the aid of Eq. 27. With the aid of the second approximation $\bar{x}_2$ we start the computation of the second approximations for all other parameters and we continue this successive approximation process until stabilization of sequences for all parameters occurs. The number of approximation steps required depends on the value of the ratio $\bar{z}/L$ and it decreases if the length $2L$ of the measured profile increases.

We turn now to the rule expressed by Eq. 14 and compute the integral of x^2K+H_1/π over the intervals $(-\infty, -L)$, (L, ∞). Denoting the integral of x^2K+H_1/π over $(-L, L)$ by $\overline{L}_2$ and observing that $H_1-\overline{H}_1=4H_1\cdot\bar{z}/\pi L$, we have

$$L_2 - \overline{L}_2 = 4L_2/\pi^2 - 6H_1\cdot(\bar{x}^2 + c_{20} - c_{02} - \bar{z}^2)/\pi L. \quad (28)$$

With the aid of Eq. 28 we deduce from Eq. 14 the important practical rule for the depth $\bar{z}$ of the center of gravity of any cross-section

$$\bar{z} = \alpha\overline{L}_2(1 + \beta\bar{z}/L)/\overline{H}_1 - \lambda\bar{x}^2/L, \quad (29)$$

where the coefficients α, β, λ are defined by $2\alpha(\pi^2-4)=\pi^2$, $(\pi^2-4)\cdot\lambda=3$, $\pi(\pi^2-4)\beta=16-\pi^2+3\pi^2(c_{02}-c_{20})/\bar{z}^2$.

For the interpretation of a magnetic survey, given the curves $X=X(x)$ and $Z=Z(x)$ in the interval $(-L, L)$, we transform the rules of Eq. 20 with the aid of Eq. 26 into

$$\tan\psi=(1 - \mu\bar{x}/L)\overline{X}_1/\overline{Z}_1; \quad IA=(1 + 4\bar{z}/\pi L)(\overline{X}_1^2 + \overline{Z}_1^2)^{1/2}/2\pi \quad (30)$$

where $\pi\overline{X}_1\overline{Z}_1\cdot\mu=4(\overline{X}_1^2+\overline{Z}_1^2)$. We also transform Eq. 20 into a form which admits for $\bar{x}$, $\bar{z}$ a numerical computation with the aid of integrals over $(-L, L)$. Multiplying Eq. 7 by x and integrating, we ex-

press $\overline{X}_1 - i\overline{Z}_1$ in terms of $\overline{L}_1$ and $\overline{H}_1$. Using the fact that $L_1 = 0$ and Eq. 23, we find that $\overline{L}_1 = 4\overline{H}_1 \cdot \bar{x} \cdot / \pi L$. Therefore

$$ik(\overline{X}_1 - i\overline{Z}_1) - 2Ie^{i\psi} \cdot \overline{H}_1 = 8IH_1 e^{i\psi} \cdot i\bar{x}/\pi L. \tag{31}$$

Integrating Eq. 7 multiplied by x^2, we find for the reduced moments $\overline{X}_2$, $\overline{Z}_2$ their expressions in terms of $\overline{L}_2$, $\overline{H}_2$. These moments being defined by

$$\overline{X}_2 = \int_{-L}^{L} (x^2 \cdot X + \overline{Z}_1/\pi) dx, \qquad \overline{Z}_2 = \int_{-L}^{L} (x^2 \cdot Z - \overline{X}_1/\pi) dx,$$

we have the relation

$$k(\overline{X}_2 - i\overline{Z}_2) = 2Ie^{i\psi} \cdot H_1 \cdot [\overline{L}_2/\overline{H}_1 - i\overline{H}_2/\overline{H}_1 + 8i\bar{x}/\pi^2]. \tag{32}$$

The relation (31) gives $2Ie^{i\psi} \cdot H_1 = ik(\overline{X}_1 - i\overline{Z}_1)[1 - 4i(\bar{x} + i\bar{z})/\pi L]$. Solving Eqs. 27 and 29 for the ratios $\overline{L}_2/\overline{H}_1$, $\overline{H}_2/\overline{H}_1$ and substituting their expressions in Eq. 32, we get in accordance with $\overline{H}_1 = H_1(1 - 4\bar{z}/\pi L)$ that

$$\bar{z} \cdot [1 - (4 + \beta\pi)\bar{z}/\pi L] + (\lambda\bar{x}^2/L) - i\bar{x} \cdot [1 - 2\lambda(1 + c_{11}/\bar{z})/L] = \alpha(\overline{X}_2 - i\overline{Z}_2)k/2Ie^{i\psi} \cdot H_1.$$

Using the notation $\overline{X}_1\overline{X}_2 + \overline{Z}_1\overline{Z}_2 = (\overline{X}_1^2 + \overline{Z}_1^2) \cdot N_x$, $\overline{X}_2\overline{Z}_1 - \overline{X}_1\overline{Z}_2 = (X_1^2 + Z_1^2) \cdot N_x$, we can write the results in the final form

$$\begin{aligned} \bar{z} &= \alpha \cdot N_x \cdot (1 + \beta\bar{z}/L) - \beta\bar{x}^2/L; \\ \bar{x} &= \alpha N_x \cdot [1 + 2(\beta\bar{z} - \lambda c_{11}/\bar{z})/L]; \end{aligned} \tag{33}$$

which is well adapted to numerical computation.

5. *Moment-functions and Moments of Squares*

The interval of integration being $(-\infty, \infty)$ and the order s of moments being a continuous variable, we define the three moment-functions M, L, H related to Dg, K, G respectively by the integrals

$$\begin{gathered} M(s) = \int_{-\infty}^{\infty} |x|^s \cdot Dg(x) dx; \quad H(s) = \int_{-\infty}^{\infty} |x|^{s+1} \cdot G(x) dx; \\ L(s) = \int_{-\infty}^{\infty} |x|^{s+1} \cdot K(x) dx. \end{gathered} \tag{34}$$

The orders of Dg, K, G at infinity are x^{-2}, x^{-2}, $|x|^{-3}$. Therefore

the variable s must be limited by the conditions: $-1<s<1$ in $M(s)$, $-2<s<0$ in $L(s)$ and $-2<s<1$ in $H(s)$. To simplify the calculations we suppose that the point O, already located by using the rules given in Section 4, is chosen as the origin of coordinate x on the profile.

We begin the study of moment-functions (34) by deducing their general expressions which hold for any form of the cross-section S. In this deduction we make use of the following lemma from analytic functions theory.

LEMMA*: "Let $F(z)$ be a rational function such that $lim\,|z^s \cdot F(z)| = 0$ both when $z \to 0$ and when $z \to \infty$.

(*i*) If $F(z)$ has no poles on the positive part of the real axis and if s' denotes the sum of residues of $(-z)^{s-1} \cdot F(z)$ at all its poles, then

$$\int_0^\infty x^{s-1} \cdot F(x)dx = \pi s' \operatorname{cosec} s\pi, \qquad (35_1)$$

the argument of the complex variable $(-z)$ involved in s' verifying the condition $|arg(-z)| < \pi$.

(*ii*) If $F(z)$ has no poles on the negative part of the real axis and if s'' denotes the sum of residues of $z^{s-1} F(z)$ at all its poles, then

$$\int_{-\infty}^0 |x|^{s-1} \cdot F(x)dx = -\pi s'' \cdot \operatorname{cosec} s\pi, \qquad (35_2)$$

the argument of z verifying the condition $|arg(z)| < \pi$."

From (3) we deduce

$$2Dg(x) = ik \iint_A [(x-\rho)(x-\bar{\rho})]^{-1} \cdot (\bar{\rho}-\rho) \cdot dS \qquad (36)$$

where $\bar{\rho} = \xi - i\zeta$ is conjugate to $\rho = \xi + i\zeta$. Integrating the product $|x|^{s-1} \cdot Dg$, we get from Eq. 36

$$2M(s-1) = 2\int_{-\infty}^{\infty} |x|^{s-1} \cdot Dg(x)dx$$

$$= ik \iint_A (\bar{\rho}-\rho)dS \int_{-\infty}^{\infty} |x|^{s-1} \cdot F(x)dx$$

* Whittaker & Watson. *Modern Analysis* (1927), Ch. VI, 6, 24, p. 117.

with $F(x)=(x-\rho)^{-1}\cdot(x-\bar{\rho})^{-1}$. If $0<s<2$, $x^s\cdot F(x)$ satisfies the condition of the Lemma. Integrating over the interval $(0, \infty)$ and using Eq. 35_1 we have

$$i\pi\int_0^\infty [(x-\rho)(x-\bar{\rho})]^{-1}\cdot x^{s-1}dx = i\pi(r+\bar{r})\cdot \operatorname{cosec} s\pi,$$

where r and $\bar{r}$ are the residues of $(-z)^{s-1}\cdot(z-\rho)^{-1}\cdot(z-\bar{\rho})^{-1}$ at the poles ρ and $\bar{\rho}$.

For all points inside the cross-section S the radius vector ρ verifies the inequalities $0<\arg\rho<\pi$, while for its conjugate $\bar{\rho}$ we have $-\pi<\arg\bar{\rho}<0$. Therefore, in calculating r and $\bar{r}$, we must choose for $z=\rho$, $-z=-\rho=e^{-i\pi}\rho$, but for $z=\bar{\rho}$, $-z=-\bar{\rho}=e^{i\pi}\cdot\bar{\rho}$ and, denoting the real part of a complex number w by $R(w)$, we have:

$$i\pi(\bar{\rho}-\rho)(r+\bar{r}) = 2\pi R[ie^{-is\pi}\cdot\rho^{s-1}]$$

$$= i(\bar{\rho}-\rho)\sin s\pi\int_0^\infty [(x-\rho)(x-\bar{\rho})]^{-1}\cdot x^{s-1}dx$$

whence

$$\int_0^\infty x^{s-1}\cdot Dg(x)\cdot dx = k\pi\cdot\operatorname{cosec} s\pi\cdot R\left[ie^{-is\pi}\iint_A \rho^{s-1}\cdot dS\right] \quad (37)$$

In the interval $(-\infty, 0)$ we apply Eq. 35_2

$$\int_{-\infty}^0 |x|^{s-1}\cdot F(x)dx = -\pi(r'+\bar{r}')\operatorname{cosec} s\pi,$$

where r' and $\bar{r}'$ are the residues of $z^{s-1}\cdot(z-\rho)^{-1}\cdot(z-\bar{\rho})^{-1}$ at ρ, $\bar{\rho}$ under the condition $|\arg(z)|<\pi$. Therefore, $r'+\bar{r}'=(\rho-\bar{\rho})^{-1}\cdot(\rho^{s-1}-\bar{\rho}^{s-1})$ and

$$i(\bar{\rho}-\rho)\int_{-\infty}^0 [(x-\rho)(x-\bar{\rho})]^{-1}\cdot|x|^{s-1}dx = 2\pi\cdot R[i\rho^{s-1}]\cdot\operatorname{cosec} s\pi;$$

$$\int_{-\infty}^0 |x|^{s-1}\cdot Dg(x)dx = k\pi\operatorname{cosec} s\pi\cdot R\left[i\iint_A \rho^{s-1}\cdot dS\right]. \quad (38)$$

Adding Eqs. 37 and 38, we have

$$\int_{-\infty}^\infty |x|^{s-1}\cdot Dg(x)dx = k\pi\cdot\operatorname{cosec}(s\pi/2)R\left[ie^{-is\pi/2}\iint_A \rho^{s-1}dS\right]$$

and, changing s into $s+1$:

$$M(s) = \int_{-\infty}^{\infty} |x|^s \cdot Dg(x) \cdot dx$$

$$= k\pi \sec(s\pi/2) \cdot R\left[e^{-is\pi/2} \cdot \iint_A \rho^s \cdot dS\right]. \qquad (39)$$

To find $H(s)$ and $L(s)$ we use Eq. 4, which gives:

$$L(s) - i \cdot H(s) = k \iint_A dS \int_{-\infty}^{\infty} |x|^{s+1} \cdot (x-\rho)^{-2} \cdot dx.$$

Applying the Lemma to the function $z^2 \cdot (z-\rho)^{-2}$, we have, if $-2 < s < 0$:

$$\int_{-\infty}^{\infty} |x|^{s+1} \cdot (x-\rho)^{-2} \cdot dx = -(s+1)\pi \cdot \csc(s\pi/2) e^{-is\pi/2} \cdot \rho^s$$

and therefore

$$\left.\begin{aligned} L(s) &= \int_{-\infty}^{\infty} |x|^{s+1} \cdot K dx \\ &= -(s+1) k\pi \csc(s\pi/2) R\left[e^{-is\pi/2} \iint_A \rho^s dS\right] \\ &\qquad (-2 < s < 0) \\ H(s) &= \int_{-\infty}^{\infty} |x|^{s+1} \cdot G dx \\ &= -(s+1) k\pi \csc(s\pi/2) R\left[ie^{-is\pi/2} \iint_A \rho^s dS\right] \\ &\qquad (-2 < s < 1) \end{aligned}\right\} . \qquad (40)$$

Proved for $-2 < s < 0$, the expression for $H(s)$ holds, by analytic continuation, if $-2 < s < 1$. It is interesting to note that if $-1 < s < 0$

$$L(s) = -(s+1) \operatorname{cotan}(s\pi/2) \cdot M(s) \qquad (41)$$

that is

$$\int_{-\infty}^{\infty} |x|^s \cdot K dx = s \cdot \tan(s\pi/2) \int_{-\infty}^{\infty} |x|^{s-1} \cdot Dg(x) \cdot dx \qquad (42)$$

$$(0 < s < 1)$$

and this relation holds, as all relations of this section, for any form of the cross-section S. If the graph of the curve $G=G(x)$ is symmetrical with respect to the origin O, the function $H(s)$ vanishes. In this case we can use instead of $H(s)$ the integral of the product $|x|^{s+1}\cdot G(x)$ in the interval $(-\infty, 0)$. In general, integrating by parts in the intervals $(-\infty, 0)$, $(0, \infty)$ we get

$$\int_{-\infty}^{0} |x|^{s+1}Gdx - \int_{0}^{\infty} x^{s+1}G\cdot dx = (s+1)\int_{-\infty}^{\infty} |x|^{s}\cdot Dg(x)dx$$
$$= (s+1)\cdot M(s)$$

and, since the sum of the two integrals in the left hand member is $H(s)$,

$$2\int_{-\infty}^{0} |x|^{s+1}Gdx = H(s) + (s+1)M(s);$$
$$2\int_{0}^{\infty} x^{s+1}Gdx = H(s) - (s+1)M(s). \tag{43}$$

This general result gives in the symmetric case when $G(-x)+G(x)=0$ and $H(s)=0$

$$\int_{-\infty}^{0} |x|^{s+1}Gdx = -\int_{0}^{\infty} x^{s+1}Gdx = (s+1)\cdot M(s)/2. \tag{44}$$

In each particular case when the cross-section S is prescribed the integral

$$e^{-is\pi/2}\cdot \iint_{A} \rho^{s}\cdot dS$$

can be calculated and expressed in terms of the parameters of the particular problem considered. Therefore each particular value of s gives us an equation in parameters of the problem and, choosing as many particular values of s as there are parameters characterizing our problem, we form a system of equations for them.

We add now the expressions of the moment functions $X(s)$ and $Z(s)$ defined for $-2<s<0$ by

$$X(s) + iZ(s) = \int_{-\infty}^{\infty} |x|^{s+1}\cdot [X(x) + i\cdot Z(x)]dx$$

and which are used in interpreting the magnetic anomaly map.

Multiplying Eq. 15 by $|x|^{\epsilon-1}$ and integrating, we have the expressions

$$\begin{aligned} kX(s) &= 2I\{H(s)\sin\psi + L(s)\cos\psi\} \\ kZ(s) &= 2I\{H(s)\cos\psi - L(s)\sin\psi\} \end{aligned} \tag{45}$$

where the inclination angle ψ can be considered as known (see Eq. 20).

It is important also to know how to compute the moments of squares Dg^2, G^2, X^2, since they are very useful in our interpretation method. Defining the first four moments of $Dg^2(x)$ by

$$D_m = \int_{-\infty}^{\infty} x^m \cdot Dg^2(x) \cdot dx \quad (m = 0, 1, 2, 3)$$

we use the expressions of the products $x^m Dg^2(x)$ in terms of quadruple integrals extended twice over the area of the cross-section S. Integrating them with respect to x in the interval $(-\infty, \infty)$, observing that

$$\int_{-\infty}^{\infty} [(x-\rho_1)(x-\rho_2)]^{-1} \cdot dx = 0,$$

$$\int_{-\infty}^{\infty} [(x-\rho_1)(x-\bar{\rho}_2)]^{-1} \cdot dx = 2\pi i(\rho_1 - \bar{\rho}_2)^{-1},$$

and using the fact that for $\epsilon = 0, 1$

$$\int_{-\infty}^{\infty} x^{\epsilon}[U_x^2 - Dg^2]dx = \int_{-\infty}^{\infty} x^{2+\epsilon} \cdot [(U_x + kA/x)^2 - Dg^2]dx = 0,$$

we get

$$2D_m = i\pi k^2 \iint_{A1} \iint_{A2} P_m(\rho_1, \bar{\rho}_2) \cdot (\rho_1 - \bar{\rho}_2)^{-1} dS_1 \cdot dS_2 \tag{46}$$

where $P_0 = 2$, $P_1 = \rho_1 + \bar{\rho}_2$, $P_2 = 2\rho_1\bar{\rho}_2$, $P_3 = (\rho_1 + \bar{\rho}_2)\rho_1\bar{\rho}_2$. Here the integrals of $x^3 Dg^2(x)$, $x^3(U_x + kA/x)^2$ and xU_x^2 over the interval $(-\infty, \infty)$ are defined as limits for $L \to \infty$ of integrals over the interval $(-L, L)$.

For $m = 0, 1, 2$ we have also

$$\int_{-\infty}^{\infty} x^m \cdot (K^2 - G^2)dx = \int_{-\infty}^{\infty} x^m \cdot K \cdot G \cdot dx = 0$$

and

$$2\int_{-\infty}^{\infty} x^m \cdot G^2 \cdot dx = i\pi k^2 \int_{\Gamma 1} \int_{\Gamma 2} P_m(\rho_1, \bar{\rho}_2) \cdot (\rho_1 - \bar{\rho}_2)^{-1} d\zeta_1 \cdot d\zeta_2,$$

$$(m = 0, 1, 2)$$

where the double line-integrals are extended twice over the boundary curve (Γ) of the cross-section S, the function $P_m(\rho_1, \bar{\rho}_2)$ being the same as above. The relations (15) give now

$$\int_{-\infty}^{\infty} x^m X^2 dx = \int_{-\infty}^{\infty} x^m Z^2 dx = 4k^{-2} \cdot I^2 \cdot \int_{-\infty}^{\infty} x^m \cdot G^2 \cdot dx \quad (m = 0, 1, 2).$$

We add another general and very important expression of Dg as the Fourier transform of a function $F(t)$ which characterizes the cross-section S

$$Dg(x) = (2\pi)^{-1/2} \cdot \int_{-\infty}^{\infty} e^{-ixt} \cdot F(t) dt. \tag{47}$$

Here

$$F(t) = k(\pi/2)^{1/2} \iint_A e^{i(\xi + i\zeta \text{ signum } t) \cdot t} \cdot dS$$

with *signum* $0 = 0$, *signum* $t = |t|/t$ for $t \neq 0$. To prove (47) it is sufficient to substitute in (3) the following expressions for $i(\rho - x)^{-1}$

$$i \cdot (\rho - x)^{-1} = \int_0^{\infty} e^{(\rho - x) it} \cdot dt = \int_{-\infty}^{0} e^{-(\rho - x) \cdot it} \cdot dt$$

and to change the order of integration over and over A, which is possible, the integral being absolutely convergent since $\zeta \geqq min\ \zeta > 0$. Applying the transform theory we get the value of the integral $I(t) = 2\pi)^{1/2} \cdot F(t)$ to be

$$I(t) = \int_{-\infty}^{\infty} e^{ixt} \cdot Dg(x) dx = \pi k \iint_A e^{-\zeta \cdot |t|} \cdot e^{i\xi t} \cdot dS. \tag{48}$$

The function $I(t)$ or its real and imaginary parts can be used for the interpretation instead of the moment function $M(s)$. It is easy to deduce the expression of $M(s)$ from Eq. 48 by applying to it the fractional integration with respect to t of order $1 - s$, $0 < s < 1$, and observing that for $t \geqq 0$

$$I(t) = \pi k \iint_A e^{i\rho t} \cdot dS. \qquad (t \geqq 0). \tag{49}$$

Therefore, for $t>0$ and $0<s<1$ we get

$$\int_{-\infty}^{\infty} x^{s-1}\cdot Dg(x)\cdot e^{ixt}\cdot dt = k\pi \iint_A e^{i\rho t}\cdot \rho^{s-1}\cdot dS.$$

Differentiating this result with respect to t and observing that after the differentiation both members are absolutely convergent integrals for $|s|<1$ we have by analytic continuation for $-1<s<1$ and $t>0$

$$\int_{-\infty}^{\infty} x^{s}\cdot Dg(x)\cdot e^{ixt}\cdot dx = k\pi \iint_A \rho^{s}\cdot e^{i\rho t}\cdot dS \qquad (|s|<1,\ t>0).$$

For $t\to 0$ we obtain the result

$$\int_{-\infty}^{\infty} x^{s}\cdot Dg(x)\cdot dx = k\pi \iint_A \rho^{s}\cdot dS \qquad (|s|<1) \qquad (50)$$

from which it is easy to deduce the expression (39) for $M(s)$, observing that in the range $(-\infty, 0)$, $x=|x|e^{i\pi}$.

The Parseval theorem for the transforms gives us also an important relation holding for $(t>0)$

$$\int_{-\infty}^{\infty} e^{ixt}\cdot Dg^2(x)\cdot dx$$

$$= i\pi k^2 \iint_{A_1}\iint_{A_2} [(\rho_1-\bar{\rho}_2)^{-1}\cdot e^{i\rho_1 t}-(e^{i\rho_1 t}-e^{i\rho_2 t})/2(\rho_1-\rho_2)]dS_1\cdot dS_2 \qquad (51)$$

from which we can easily deduce another proof of the results expressed by Eq. 46.

For G we have an expression similar to Eq. 47,

$$G(x) = (2\pi)^{-1/2}\cdot \int_{-\infty}^{\infty} e^{-ixt}\cdot g(t)dt, \qquad (52)$$

where $g(t)$ is expressed by a line integral extended over the boundary curve (Γ) of the cross-section S,

$$g(t) = k(\pi/2)^{1/2}\cdot \int_\Gamma e^{-\xi\cdot|t|}e^{i\xi t}\cdot d\zeta.$$

Finally we point out the expression

$$K(x) = (2\pi)^{-1/2} \int_{-\infty}^{\infty} e^{-ixt} \cdot l(t) \cdot dt \tag{53}$$

where

$$l(t) = g(t) \cdot e^{-i(\pi/2) \cdot \text{signum } t}.$$

The formulae (52), (53) give corresponding expressions for $X(x)$, $Z(x)$, and the transform theory applied to all these expressions gives the general rules for computing integrals which are very useful in the interpretation.

6. *Interpretation of Geophysical Measurements Made Above a Symmetric Anticline*

Gravity map. Among the seven parameters $\bar{x}$, p, k, α, β, γ, δ the first, $\bar{x}$, is given by Eq. 27, Section 4, which in the symmetric case ($c_{11}=0$) reduces to

$$\bar{x} = (1 + 2\bar{h}/\pi L) \cdot \overline{M}_1/\overline{M}_0. \tag{54}$$

Using $\overline{M}_1/\overline{M}_0$ as its first value we can plot the first position O_1 of the point O. The value πkA of M_0 is now $\pi \cdot k(A_1 - A_2)$, A_1 and A_2 being the areas of the sections $C'ACDBD'C'$ and $C'CDD'C'$ (Fig. 2) respectively, since to the last one we have ascribed the negative density contrast $-\sigma$. Therefore $M_0 = 2\pi f\sigma(\lambda - 1)T$ and for σ we have the rule

$$\sigma = k/2f = \overline{M}_0(1 + 2\bar{r}/\pi L)/2\pi f \cdot (\lambda - 1) \cdot lT. \tag{55}$$

Expressing p, T, q, λ as functions of l, α, β, γ, δ we obtain $T = l \cdot \sin(\gamma - \delta) \cdot \csc\gamma \cdot \csc\delta$, $p = l \cdot \sec\alpha \cdot \csc\gamma \cdot \cos(\alpha + \gamma)$, $q = l \cdot \tan\alpha$, $\lambda = 1 + \sec\alpha \cdot \sec\beta \cdot \sin\gamma \cdot \sin\delta \cdot \sin(\alpha - \beta) \cdot \csc(\gamma - \delta)$. We can consider the interpretation problem as solved if the values of five parameters l, α, β, γ, δ are found. Calculating the explicit expression of the function $M(s)$ for $-1 < s < 1$, we will use the abbreviations $\psi(s)$, $f(s)$. These functions of four parameters α, β, γ, δ and of the number s are defined by $\psi(s) = \psi(s;\ \alpha,\ \gamma)$

$$= \sin\alpha \cdot \csc^{2+s}\gamma \cdot [\cos^{2+s}(\alpha + \gamma) \cdot \sec^{1+s}\alpha - \cos(\alpha + 2\gamma + s\gamma)]$$

and $f(s) = f(s;\ \alpha,\ \beta,\ \gamma,\ \delta)$

$$= 2\pi \sec(s\pi/2) \cdot [(1 + s)(2 + s)]^{-1} \cdot [\psi(s;\ \alpha,\ \gamma) - \psi(s;\ \beta,\ \delta)].$$

With these notations we have the result:

$$M(s) = k\pi \sec(s\pi/2)R\left\{e^{-is\pi/2}\cdot\left[\iint_{A_1}\rho^s dS - \iint_{A_2}\rho^s\cdot dS\right]\right\}$$
$$= k\cdot l^{2+s}\cdot f(s). \tag{56}$$

In particular, $\psi(0;\ \alpha,\ \gamma)=\tan\alpha$, $f(0)=\pi(\tan\alpha-\tan\gamma)$, and $\psi(1;\ \alpha,\ \gamma)=\tan\alpha\cdot(3\ \operatorname{ctn}\gamma-\tan\alpha)$. Therefore

$$M_0 = M(0) = \pi kl^2\cdot\sin(\alpha-\beta)\cdot\sec\alpha\cdot\sec\beta. \tag{57}$$

The depth $\bar{z}$ of the center of gravity is a function of l, α, β, γ, δ and, defining the function $\phi=\phi(\alpha,\beta,\gamma,\delta)$ by

$$\phi=\phi(\alpha,\beta,\gamma,\delta)=3^{-1}\cdot\cos\alpha\cdot\cos\beta\cdot\csc(\alpha-\beta)\left[\psi(1;\alpha,\gamma)-\psi(1;\beta,\delta)\right],$$

we have for $\bar{z}$ the rule $\bar{z}=l\cdot\phi$, that is

$$\bar{z} = p + (\lambda+2)T/3 - (4-\lambda)q/3(\lambda-1) = l\cdot\phi(\alpha,\beta,\gamma,\delta). \tag{58}$$

Now every numerical value of $s\neq 0$ between -1 and 1 yields an equation in five unknowns l, α, β, γ, δ, since the numerical value of $M(s)$ can be computed with the aid of a planimeter, using the experimental curve $Dg=Dg(x)$. This curve being known only over the interval $(-L,\ L)$, a correction is necessary. The difference $M(s)-\overline{M}(s)$, where $\overline{M}(s)$ is the moment function reduced to the finite integration interval $(-L,\ L)$, is proportional to $(l/L)^{1-s}$. Therefore the negative values of s are better suited for interpretation, the correction needed being much smaller. Once and for all we fix the five values of s defined by $s=-m/8$, $m=3,\ 4,\ 5,\ 6,\ 7$. We then have five equations of the general type $M(s)/M_0=l^s\cdot f(s)/f(0)$, and eliminating l, we can reduce them to a system of four equations in four unknowns α, β, γ, δ. Each of them is of the form $E(\alpha,\beta,\gamma,\delta)=n$, where the known number n denotes $M^r(s)\cdot M^{-s}(r)\cdot M_0^{s-r}=n$, the function E being defined by $E=f^r(s)\cdot f^{-s}(r)\cdot f^{s-r}(0)$. For $j=1,\ 2,\ 3,\ 4$ we can define E_j by fixing the values of s, r and letting $s=s_j$, $r=r_j$. For instance, we choose once and for all $s_1=-.875$; $s_2=r_1=-.75$; $s_3=r_2=-.625$; $s_4=r_3=-.5$ and $r_4=-.375$. The tabulation of the functions E_j is facilitated by the fact that in general

$$E \equiv C_{rs}\cdot\left(\frac{\sin(\alpha-\beta)}{\cos\alpha\cos\beta}\right)^{s-r}\cdot\frac{[\psi(s;\alpha,\gamma)-\psi(s;\beta,\delta)]^r}{[\psi(r;\alpha,\gamma)-\psi(r;\beta,\delta)]^s}, \tag{59}$$

the constant C_{rs} being defined by

$$2^s \cdot [(1+s)(2+s) \cdot \cos(s\pi/2)]^r \cdot C_{rs} = 2^r \cdot [(1+r)(2+r) \cos(r\pi/2)]^s.$$

Therefore it is advisable to plot the graphs of five families $\psi(s; x, y) = \text{constant}$, for $s = -m/8$, $m = 3, 4, 5, 6, 7$. Solving the system of four equations in four unknowns

$$E_j(\alpha, \beta, \gamma, \delta) = n_j, \qquad (j = 1, 2, 3, 4), \tag{60}$$

we find the values of $\alpha, \beta, \gamma, \delta$. Any moment-function $M(s)$ now gives l since in general

$$l^s = f(0; \alpha, \beta, \gamma, \delta) \cdot M(s)/M_0 \cdot f(s; \alpha, \beta, \gamma, \delta),$$

and σ is given by Eq. 55.

Now, the curve $Dg = Dg(x)$ being known only over the range $(-L, L)$, the numbers n in Eq. 60 defined by $n = M^r(s) \cdot M^{-s}(r) \cdot M_0^{s-r}$, must be replaced in the first approximation by $\bar{n}$, defined as $\bar{n} = \overline{M}^r(s) \cdot \overline{M}^{-s}(r) \cdot \overline{M}_0^{s-r}$. Denoting the solution of the system $E_j = \bar{n}_j$ by $\alpha_1, \beta_1, \gamma_1, \delta_1$ we deduce with their aid l_1 and the first corresponding value $\bar{z}_1$, using the rule expressed by Eq. 58. To improve these first values by means of the process of successive approximations we must evaluate the difference $M(s) - \overline{M}(s)$. For $|x| \geqq L$, the profile being sufficiently long on both sides of the axis of the anomaly (the anticlinal axis), for the gravitational action of the anticline can be substituted that of a horizontal line source at the depth $\bar{z}$, so that for $|x| \geqq L$ we can use the approximate formula

$$Dg(x) \sim M_0 \cdot \bar{z}[\pi(x^2 + \bar{z}^2)]^{-1} \qquad (|x| \geqq L). \tag{61}$$

Therefore, neglecting the terms of relative order $(\bar{z}/L)^2$,

$$M(s) - \overline{M}(s) = 2M_0 \cdot \bar{z}L^{s-1}/\pi(1 - s)$$

and for $M(-s)$ the reduction formula is

$$M(-s) = \overline{M}(-s) + 2M_0\bar{z}/\pi(1 + s)L^{s+1}, \qquad (s > 0), \tag{62}$$

where $M_0 = \overline{M}_0(1 - 2\bar{z}/\pi L)^{-1}$. With the aid of $l_1, \alpha_1, \beta_1, \gamma_1, \delta_1$ we can compute, using (Eq. 62), the improved values of $M(-s)$, and deduce the improved second approximations for the second members n_j of Eqs. 60, as well as improve the position of the point O. Solving anew the system (60) with new values of second members, we deduce the set of second approximations for our five parameters $l, \alpha, \beta, \gamma, \delta$ which, in turn, used in Eq. 62, gives us better values for the second mem-

bers n_j in (60). This process is to be continued until stabilization of the values of the four parameters α, β, γ, δ occurs. Substituting the final values into the expression (56) for the moment function $M(s)$ for any fixed value of s other than the five values $8s = -m$, $m = 3, 4, \cdots 7$, and comparing the result thus obtained with the experimental value of the same $M(s)$ given by Eq. 62 where $\overline{M}(s)$ is computed by means of a planimeter, we have a control on our results.

The solution of the system (60) can be facilitated, if a set of charts of four families $E_1(\alpha, \beta; x, y) = \text{constant}$, $E_2(\alpha, \beta; x, y) = \text{constant}$, $E_3(\alpha, \beta; x, y) = \text{constant}$, $E_4(\alpha, \beta; x, y) = \text{constant}$ is plotted for different values of α and $\beta < \alpha$. To four experimental data n_1, n_2, n_3, n_4 correspond four curves (60) on each chart for $\alpha = 5°$, $10°$, $15° \cdots$ up to $\alpha = 85°$; $\beta = 0°$, $5°$, $\cdots < \alpha$. These four curves form on every chart a curvilinear quadrilateral, whose area considered as a function of α, β must vanish for the values $\alpha = \bar{\alpha}$, $\beta = \bar{\beta}$, roots of the equations (60); the coordinates $\bar{x}$, $\bar{y}$ of the intersection point $(\bar{x}, \bar{y})$ common to these four curves being two other roots $\bar{\gamma} = \bar{x}$, $\bar{\delta} = \bar{y}$ of Eqs. 60. Consequently, in practice, we have two such charts (α', β') and (α'', β'') with $\alpha'' = \alpha' + 5°$, $\beta'' = \beta' + 5°$, such that the above quadrilaterals have the smallest areas on these two charts. It is plain that $\alpha' < \bar{\alpha} < \alpha''$, $\beta' < \bar{\beta} < \beta''$ and $\bar{\gamma}$, $\bar{\delta}$ are given approximately by the coordinates of the center of gravity of the quadrilateral. More precise results are thereafter obtained, plotting the set of charts for $\alpha = \alpha' + 1°$, $\alpha' + 2°$, $\alpha' + 3°$, $\alpha' + 4°$ and $\beta = \beta' + 1°$, $\beta' + 2°$, $\beta' + 3°$, $\beta' + 4°$ and studying the same quadrilaterals on these detailed charts.

Another interpretation can be based on the use of the function $I(t)$ (Eq. 48) for different values of the positive constant t which has the dimensions of $(length)^{-1}$. Its explicit expression in our symmetric case is

$$\int_{-\infty}^{\infty} Dg(x) \cdot \cos xt \cdot dx$$

$$= I(t) = 2k\pi t^{-2} \cdot e^{-(p+q)t} \cdot [\Phi(\alpha, lt) - e^{-t.T} \cdot \Phi(\beta, lt)] \quad (63)$$

where

$$\Phi(\alpha, u) = \sin \alpha \cdot [\cos \alpha \cdot e^{u \cdot \tan \alpha} - \cos (\alpha - u)]. \quad (64)$$

To find the four unknowns α, β, l, T we form the system of four equations

$$Q_j(\alpha, \beta, l, T) = m_j, \qquad (j = 1, 2, 3, 4) \quad (65)$$

where $m = 2^{t-s} \cdot I^s(t) \cdot I^{-t}(s) \cdot M_0{}^{t-s}$ are known numbers, the functions Q_j being defined by

$$Q(\alpha, \beta, l, T) = [\Psi(t)]^s \cdot [\Psi(s)]^{-t} \tag{66}$$

where

$$(lt)^2 \cdot \sin(\alpha - \beta) \cdot \Psi(t) = [\Phi(\alpha, lt) - e^{-tT} \cdot \Phi(\beta, lt)] \cos\alpha \cdot \cos\beta.$$

Choosing once and for all the eight constants t_j, s_j $(j = 1, 2, 3, 4)$ and using Eqs. 64 and 66 we can tabulate the four functions Q_j. On the other hand the numbers m_j are computed with the aid of the experimental curve $Dg = Dg(x)$. Solving the system (65) by successive approximation we achieve the interpretation. This solution proceeds exactly as that of Eq. 60 where instead of Eq. 62 we use the reduction formula

$$I(t) = \bar{I}(t) - 2M_0\bar{z}[\sin(tL) - 2\cos(tL)/tL]\pi tL^2, \tag{67}$$

where as always $\bar{I}(t)$ denotes the integral of $Dg(x) \cos xt \cdot dt$ over the interval $(-L, L)$. Knowing the values of α, β, l, T, we deduce $q = l \cdot \tan\alpha$, $\lambda = 1 + (q - l\tan\beta)/T$ and the value of p is given by Eq. 63 using any $I(t_j)$. The parameters $\bar{z}$ and σ are found with the aid of Eqs. 58 and 55.

Thus, each of two independent methods, based on $M(s)$ and $I(t)$ respectively, yields the numerical values of all parameters involved, locating the apex A, determining the slope α, thickness T and λT, depth of base $p+q$, width $2l$ of the symmetric anticline, and giving the density contrast σ, deduced from the geophysical measurements.

Gradient Map

A gradiometer (torsion-balance with three masses) is a much more precise apparatus than the ordinary torsion-balance. While it gives only U_{xz} and U_{yz}, being insensitive to the curvature components U_Δ and $2U_{xy}$, this is compensated for by the fact that the gradient components are given with the remarkable precision of a half-Eötvös unit $(.5 \times 10^{-9}$ cgs.).

With this apparatus a map of the gradient is obtained and we proceed to study its interpretation in our symmetric case. Since $H(s) = 0$ we use instead of the moment-function $M(s)$ the integral $h(s)$ defined by

$$h(s) = \int_{-\infty}^{\infty} |x|^{s+1} \cdot |G(x)|\, dx = (s+1)M(s) = (s+1)kl^{2+s} \cdot f(s) \tag{67}$$
$$(-3 < s < 1)$$

The moment H_1 replaces M_0 and $h(0) = h_0 = -H_1 = M_0$.

Nothing is changed in the general procedure of interpretation except for the tables of functions used, charts and some formulas. Thus, for instance, Eqs. 60 and 62 are replaced respectively by

$$E_j'(\alpha, \beta, \gamma, \delta) = n_j', \qquad (j = 1, 2, 3, 4) \tag{60'}$$

$$h(-s) = \bar{h}(-s) + 4h_0\bar{z}/\pi(1+s)L^{s+1}, \tag{62'}$$

where $E' = (1+s)^r(1+r)^{-s}E$, $n' = h^r(s)\cdot h^{-s}(r)\cdot h_0^{s-r}$, $\bar{h}(s)$ denoting the integral of Eq. 67 but taken over the finite interval $(-L, L)$ rather than over $(-\infty, \infty)$. The successive approximation process is applied to six parameters $\alpha, \beta, \gamma, \delta, l, \bar{x}$. For the last one the formula of Eq. 28, Section 4, is to be used. The moment $\overline{H}_2$ involved in it is always defined as an integral over $(-L, L)$ instead of over $(-\infty, \infty)$. We observe that s can now take all values between -3 and 1. For $s=-2$ we must use the fact that

$$\theta(\alpha, \gamma) = \lim_{s\to -2}\left[(2+s)^{-1}\cdot\psi(s)\right]$$

$$= \sin\alpha\cos\alpha\left[\gamma\tan\alpha + \log\cos(\alpha+\gamma) - \log\cos\alpha\right]$$

which gives for $h(-2)$ the special formula

$$h(-2) = -k\lim_{s\to -2} f(s) = 2\pi k\left[\theta(\beta, \delta) - \theta(\alpha, \gamma)\right].$$

The arguments $\cos(\alpha+\gamma)$, $\cos(\beta+\delta)$ of logarithms are always positive since $\alpha+\gamma<90°$, $\beta+\delta<90°$. To diminish the importance of the correction for the range of the infinite integrals $(-\infty, -L)$, (L, ∞) it is advisable to use, as values s_j, numbers in the interval $-3<s_j\leqq -2$. The function

$$H(t) = \int_{-\infty}^{\infty} G(x)\cdot\sin xt\cdot dx \tag{68}$$

can also be used for the interpretation of the gradient map since integrating by parts we have

$$H(t) = -t\int_{-\infty}^{\infty} Dg(x)\cdot\cos xt\cdot dx = -t.I(t).$$

The system (65) is to be solved with the only difference that its second members m_j must be computed by the rule

$$m = s^t\cdot t^{-s}\cdot H^s(t)\cdot H^{-t}(s),$$

the reduction formula for $H(t)$ being

$$H(t) = \overline{H}(t) + 2h_0\bar{z}\left[\sin(tL) - 4\cos(tL)/tL\right]/\pi L^2.$$

Torsion Balance Map

If we have to interpret the two curves $G=G(x)$ and $K=K(x)$, the first approximate values for $\bar{x}$ and $\bar{z}$ are given by the results of Eqs. 28 and 30 of Section 4. It is interesting to observe that a control of the value of $\bar{x}$ is obtained by using the moments of the product GK. Defining them by

$$\Pi_n = \int_{-\infty}^{\infty} x^n \cdot G(x) \cdot K(x) \cdot dx$$

we find easily that the first three moments Π_0, Π_1, Π_2 are zero, but

$$2\Pi_3 = -\pi k^2 A^2, \qquad \Pi_4 = -2\pi k^2 A^2 \cdot \bar{x}$$

which gives the relation

$$\bar{x} = \Pi_4/4\Pi_3$$

The reduction to the finite interval $(-L, L)$ in our symmetric case is

$$\overline{\Pi}_3 = \int_{-L}^{L} x^3 GK dx \cong \Pi_3 \cdot (1 - 8\bar{z}/\pi L), \quad \overline{\Pi}_4 = \int_{-L}^{L} x^4 KG dx \cong \Pi_4$$

which yields the important formula

$$\bar{x} = (1 + 8\bar{z}/\pi L)\overline{\Pi}_4/4\overline{\Pi}_3. \tag{69}$$

The five parameters l, α, β, γ, δ can be found with the aid of the experimental curve $K=K(x)$ and this controls the set of values of the same parameters obtained by interpreting the curve $G=G(x)$.

For $-1<s<0$ we have in general

$$L(s) = \int_{-\infty}^{\infty} |x|^{s+1} \cdot K(x) dx = -(s+1) \cot(s\pi/2) \cdot M(s). \tag{70}$$
$$(s \neq -1)$$

In our symmetric case substituting for $M(s)$ its expression (56), we obtain for $L(s)$ the expression which holds by analytical continuation for $-2<s<0$

$$L(s) = 2\pi(2+s)^{-1} \cdot k \cdot \csc(s\pi/2) \cdot l^{2+s} [\psi(s; \beta, \delta) - \psi(s; \alpha, \gamma)] \tag{71}$$
$$(-2 < s < 0).$$

Eqs. 60 are now replaced by

$$E_j''(\alpha, \beta, \gamma, \delta) = n_j'', \qquad (j = 1, 2, 3, 4) \tag{72}$$

where $n'' = L^r(s) \cdot L^{-s}(r) \cdot h_0^{s-r}$ and the function E'' can be defined as E by Eq. 59 with the only difference being that the constant C_{rs} in (59) is to be replaced by C_{rs}'', this coefficient being defined by $2^s \cdot (2+s)^r \cdot |\sin(s\pi/2)|^r \cdot C_{rs}'' = 2^r \cdot (2+r)^s \cdot |\sin(r\pi/2)|^s$. The reduction formula for $L(-s)$ is

$$L(-s) = \overline{L}(-s) + 2h_0/\pi s L^s.$$

We add two control relations obtained comparing the moments H_1, H_2, Π_3 and Π_4. Reducing them to the interval $(-L, L)$, we have

$$2\overline{\Pi}_3 + \overline{H}_1^2 = 0, \qquad \pi \cdot \overline{\Pi}_4 + \overline{H}_1 \cdot \overline{H}_2 = 0.$$

It is also possible to use for the interpretation the function $K(t)$ defined by the integral

$$K(t) = \int_{-\infty}^{\infty} K(x) \cos(xt) \cdot dx.$$

In our symmetric case the integral of the product $K(x) \cdot \sin(xt)$ is zero and therefore the transform theory shows (see Eq. 53) that $K(t) = (2\pi)^{1/2} \cdot l(t)$. For $t \geqq 0$ we have $l(t) = g(t)$ and also $K(t) = H(t)$, since $H(t) = (2\pi)^{1/2} \cdot g(t)$. The relation

$$\int_{-\infty}^{\infty} K(x) \cdot \cos(xt) \cdot dx = \int_{-\infty}^{\infty} G(x) \cdot \sin(xt) \cdot dx \qquad (t \geqq 0)$$

which holds only in a symmetric case for $t \geqq 0$, proves that all that has been said on the use of $H(t) = -t \cdot I(t)$ can be repeated for the K-map, using $K(t)$ instead of $H(t)$. The reduction formula for $K(t)$ is

$$K(t) = \overline{K}(t) - 2h_0 \cdot [\sin(tL) - 2\cos(tL)/tL]/\pi t L^2.$$

Magnetic Maps

Eqs. 30 and 33 give the rules for computing the parameters $\bar{x}$, $\bar{z}$, ψ and IA. Their first values are obtained by omitting in Eq. 33 in the expression for β as defined following Eq. 29, c_{02} and c_{20} ($c_{11} = 0$ in the symmetric case). To find the other five parameters we will use instead of $M(s)$, $h(s)$ or $L(s)$ the moment functions $X(s)$, $Z(s)$ defined in Section 5. In our case $H(s) = 0$ and Eq. 45 becomes, using the value of M_0 given by Eq. 57:

$$X(s) = 2\pi IA \cos\psi \cdot L(s)/M_0, \qquad Z(s) = -2\pi IA \cdot \sin\psi \cdot L(s)/M_0.$$

Since $L(s)$ is given by (71) and $2\pi IA$ and ψ are known, it is plain that each of these two functions $X(s)$ and $Z(s)$ can serve for the interpretation in the same way that $M(s)$ serves for a gravity map. According to Eq. 15 their reduction formulae are

$$X(-s) = \overline{X}(-s) + 4IA \cos\psi/sL^s,$$
$$Z(-s) = \overline{Z}(-s) - 4IA \sin\psi/sL^s.$$

The interpretation can be based also on the use of any one of four functions $X_c(t)$, $X_s(t)$, $Z_c(t)$, $Z_s(t)$ defined by the integrals

$$X_c(t) + iX_s(t) = \int_{-\infty}^{\infty} X(x)e^{ixt}dx, \qquad Z_c(t) + iZ_s(t) = \int_{-\infty}^{\infty} Z(x)e^{ixt}dx.$$

In fact, with the aid of Eq. 15 it is easy to prove that in our symmetric case, where the integrals over the interval $(-\infty, \infty)$ of $G(x)\cos(xt)$ and $K(x)\sin(xt)$ are zero, all these four functions reduce to $H(t)$:

$$k[Z_s(t) - iZ_c(t)] = k[X_c(t) + iX_s(t)] = 2Ie^{i\psi}\cdot H(t) \qquad (t \geqq 0).$$

Therefore any one of them can be used in the interpretation of a magnetic map in exactly the same way that $H(t)$ is used for a gravitational map. We note the relation

$$\tan\psi = X_s(t)/X_c(t) = -Z_c(t)/Z_s(t) \qquad (t \geqq 0).$$

which holds for any positive value of t. The reduction formulae for our four functions are

$$-(X_c - \overline{X}_c)/\cos\psi = (Z_c - \overline{Z}_c)/\sin\psi$$
$$= 4IA[\sin(tL) - 2\cos(tL)/tL]/tL^2$$
$$(X_s - \overline{X}_s)/\sin\psi = (Z_s - \overline{Z}_s)/\cos\psi$$
$$= 4\bar{z}IA[\sin(tL) - 4\cos(tL)/tL]/L^2.$$

When the interpretation is achieved the values of all parameters are known and the areas A_1 and A_2 can be computed. Therefore the parameter $A = A_1 - A_2$ is given by the interpretation of a magnetic map and the intensity of magnetization I is obtained dividing the value of the parameter IA by that of the area A.

CONCLUSION

In the foregoing an outline is given of a new mathematical method

for the interpretation of the maps of magnetic and gravitational anomalies. These methods are general, and they are applicable to all possible cases of two-dimensional or centrally symmetric anomalies observed in any of the various types of gravitational and magnetic measurements. Based on the use of average values only, they yield quantitative interpretation, the determination of density contrast and magnitude and direction of the magnetization-vector included. They do not depend on the existence of well-pronounced maxima and they are applicable equally well to small anomalies. We confined our discussion to the particular case of a symmetric anticline in order to carry it out with enough detail to make the concrete application of our methods in this particular case as clear as possible. It is important to emphasize that, in general, the application of such quantitative methods presupposes an accurate correction for the regional anomaly, but cannot be expected to yield good results if this correction is made, as is customarily done, simply by arbitrarily smoothing the experimental curves.

These methods, including the solution of the problem (*A*) (see *Introduction*) which is not treated in this paper, have been applied by the author to the practical interpretation of field-problems of various kinds.

PRECISE MEASUREMENT OF DEEP ELECTRICAL ANOMALIES*

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ABSTRACT

A method of electrical prospecting has been developed in which the deleterious effects of superficial inhomogeneities in resistivity are eliminated. An electrode configuration is used consisting of a current electrode at "infinity," a pair of current electrodes with a constant separation of a few hundred feet which are used alternately, and a pair of potential electrodes with a constant separation of a few hundred feet, collinear with the pair of current electrodes, and at a distance from them which is varied to secure depth resolution.

It is demonstrated that superficial influences are eliminated by forming the resistivity increment, the ratio between apparent resistivity determined by use of the closer current electrode of the alternate pair and that determined by use of the farther current electrode of the alternate pair. It is also demonstrated that the area explored is below a point approximately half-way between the alternate pair of current electrodes.

Resistivity increment curves, called *Resistologs* by the authors, can be correlated from station to station, and after they are correlated the lateral variation in the electrical properties of selected subsurface zones can be studied. As a result of the latter characteristic of the measurements, a possibility exists for the direct location of oil and gas, observational evidence for which is presented.

The results of surveys made in Hart County, Kentucky, and in the Sam Fordyce, Seven Sisters, Pettus, Branyon, Dunlap, Oakville, and Rhode Ranch fields of Southwest Texas are displayed.

INTRODUCTION

This paper is the first publication of results of a research on electrical prospecting extending over a period of ten years. It became apparent early in this work that the effects of shallow inhomogeneities were the fundamental barrier to the practical extension of electrical methods to greater depths and smaller anomalies. This work may therefore be characterized as primarily a study of the nature of such inhomogeneities and the invention and experimental investigation of various schemes for eliminating the influence of such undesired anomalies from the final results. Quite a number of such procedures were investigated during this time. This discussion is confined to the procedure showing the greatest promise of practical application.

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The method of investigation has been primarily experimental. The procedure was first investigated on a small scale using a water-filled test pond over which the electrode system was suspended by a framework. This permitted the insertion and removal of inhomogeneities of various types without other change of conditions. After completing small scale experiments this procedure was extensively investigated under field conditions on an experimental and semiexperimental basis. In field investigation it was endeavored to go beyond the usual procedure of accepting apparent agreement between experimental data and known or subsequently determined subsurface data as final proof of validity. Auxiliary tests were applied in each of such cases which were designed to determine whether results were explained by shallow inhomogenieties or other common sources of error.

The necessity of relying almost entirely upon experimental investigation of electrical methods in general is well indicated by the complexity and diversified nature of the various phenomena known to be involved. The conduction of electric current in the earth is electrolytic in nature. Current flow results because of actual movement of the positive and negative ions into which formation electrolytes dissociate. Subsurface anomalies result because of the existence of the following electro-chemical phenomena, although the relative importance of each has never been ascertained.[1]

(1) Polarization at the interface of formations containing different quantities of electrolyte per unit volume.

(2) Polarization at the interface of formations containing electrolytes of different concentrations.

(3) Polarization at the interface of formations containing different electrolytes.

(4) The presence of a medium which is permeable to some species of ions and not to others. The relations existing when two solutions are separated by a membrane which is non-permeable to an ion, or ions, in one solution have been investigated extensively in connection with biological processes. Equilibrium occurs with the diffusible ions distributed in accord with Donnan's Equilibria.[2] Because of the decrease in porosity of shales with depth[3], anomalies from this source should increase in importance with depth.

[1] Creighton and Fink. *Electrochemistry*, Vol. 1.

[2] Bodansky. *Physiological Chemistry*, p. 22.

[3] Athy, L. F. A.A.P.G. Bulletin, Vol. 14, No. 8, 1930.

The presence of non-diffusible ions or charged particles appears to be a possible explanation of most of the potential difference variation of the "porosity" curve of electric well logs. For example, the anomalous flow of current resulting when two electrolytes of different concentration are separated by a shale section so as to simulate the condition existing between a sand, shale, and a penetrating well, may be explained theoretically if the shale is impermeable to ions which are more concentrated in one electrolyte than the other, or to non-diffusible colloidal material which is dissolved from the shale to a greater extent by one electrolyte than the other. Anomalous current flow under the above conditions and its relation to electrical logging has been studied experimentally by Mounce and Rust.[4]

SMALL SCALE EXPERIMENTAL DATA

Fig. 1 illustrates by small scale experiment the influence of shallow inhomogeneities on apparent resistivity data. The electrode system consists of two fixed current electrodes and a series of fixed potential electrodes along the extension of the line determined by the current electrodes. Connection was made to one pair of potential electrodes at a time, the separation between current and potential electrodes having been varied by making connection between different pairs of potential electrodes. A means was thus provided by which a given series of potential electrode positions could be accurately duplicated as to separation between potential and current electrodes. This electrode system was suspended over a water pond and in contact with the water. The water level was maintained constant and the pond shielded from air currents. A commutator by which potential and current leads were simultaneously reversed was used for overcoming polarization effects at electrodes. Potential electrodes were 6 cm apart in all cases and were moved by 6 cm increments. This arrangement provides a means for insertion and removal of inhomogeneities without other change of condition. Since the apparent resistivity curve for the water pond was an approximately straight horizontal line with all inhomogeneities removed, the influence of the inhomogeneity was readily apparent by inspection.

It will be noted that the shallow inhomogeneity produces a resistivity maximum which might be interpreted as resulting from a relatively deep high resistive subsurface layer, if all maxima are interpreted as resulting from horizontal subsurface layers.

[4] Mounce and Rust. A.I.M.E. *Technical Publication No. 1626.*

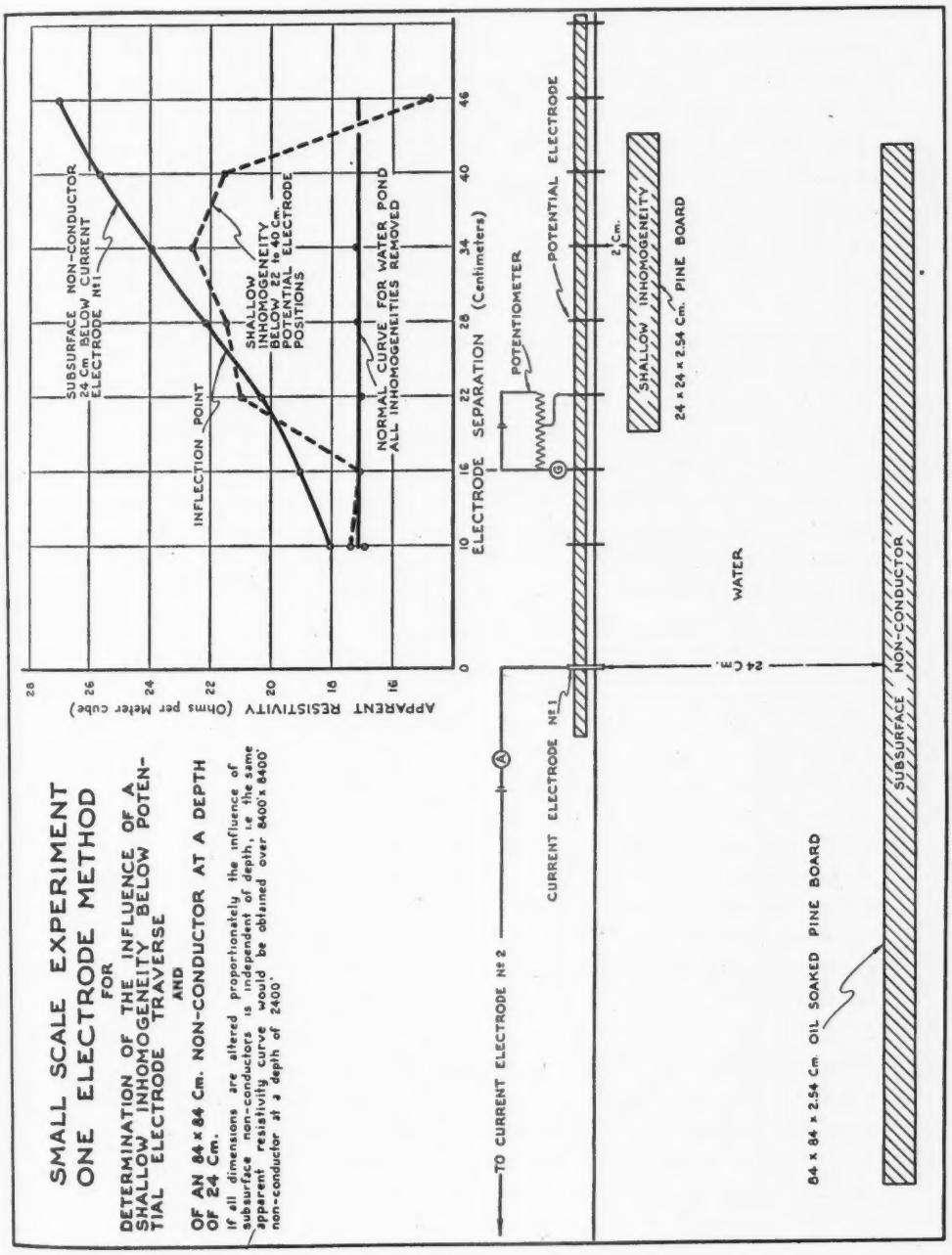

SMALL SCALE EXPERIMENT
ONE ELECTRODE METHOD
FOR
DETERMINATION OF THE INFLUENCE OF A SHALLOW INHOMOGENEITY BELOW POTENTIAL ELECTRODE TRAVERSE
AND
OF AN 84 x 84 Cm. NON-CONDUCTOR AT A DEPTH OF 24 Cm.
If all dimensions are altered proportionately the influence of subsurface non-conductors is independent of depth, i.e the same apparent resistivity curve would be obtained over 8400 x 8400 non-conductor at a depth of 2400.
APPARENT RESISTIVITY (Ohms per Meter cube)
SUBSURFACE NON-CONDUCTOR 24 Cm BELOW CURRENT ELECTRODE N°1
INFLECTION POINT
SHALLOW INHOMOGENEITY BELOW 22 to 40 Cm. POTENTIAL ELECTRODE POSITIONS
NORMAL CURVE FOR WATER POND ALL INHOMOGENEITIES REMOVED
ELECTRODE SEPARATION (Centimeters)
TO CURRENT ELECTRODE N° 2
CURRENT ELECTRODE N°1
POTENTIOMETER
POTENTIAL ELECTRODE
2 Cm.
SHALLOW INHOMOGENEITY
24 x 24 x 2.54 Cm. PINE BOARD
24 Cm.
WATER
84 x 84 x 2.54 Cm. OIL SOAKED PINE BOARD
SUBSURFACE NON-CONDUCTOR

FIG. 1. Small scale experiment illustrating the influence of shallow inhomogeneities on apparent resistivity measurements.

It will also be noted that the apparent resistivity curve obtained over the deeper inhomogeneity indicates that the resistivity maximum will be at an electrode separation somewhat greater than twice the depth. This curve has an inflection point at about 25 cm corresponding to a depth to the inhomogeneity of 24 cm. Such inflection points have been utilized as a basis for correlation and interpretation of field results which will be subsequently described.

PROCEDURE EMPLOYED FOR ELIMINATING THE INFLUENCE OF SHALLOW INHOMOGENEITIES

The method for eliminating the influence of the shallow inhomogeneities along the potential electrode traverse is illustrated by Fig. 2. *A* shows the type of apparent resistivity curve obtained if current electrodes remain stationary and potential electrodes are moved across a shallow inhomogeneity for otherwise homogeneous conditions. If the potential electrodes are now placed on or near the shallow inhomogeneity and electrode separation varied by moving current electrode *1*, the potential electrodes and distant current electrode *3* remaining stationary, a curve such as shown at *B*, Fig. 2 is obtained. This curve is an approximately horizontal straight line except for relatively small electrode separation. It is evident that for electrode separations great enough to be on the flat portion of this curve the influence of the shallow inhomogeneity is approximately independent of electrode separation. This fact is utilized for eliminating the influence of shallow inhomogeneities from the data by the procedure shown at *C*, Fig. 2.[5] An additional current electrode *2* is placed in the vicinity of 1, preferably along the line determined by *1* and the potential electrodes. For each position of the potential electrodes two measurements of potential difference are made, one with current flow between *1* and *3* and the other with current flow between *2* and *3*. These two potential difference values along with corresponding current values and electrode separations provide data from which two apparent resistivity curves R_1 and R_2 may be plotted. For electrode separations *a* of interest in deep prospecting switching from *1* to *2* results in varying the electrode separation by the distance between these electrodes along the flat portion of the curve of *B* of Fig. 1. Obviously no appreciable change in the influence of any inhomogeneity which might be present in the vicinity of the potential electrodes results from this operation. A ratio

[5] U. S. Patents #2,231,048 and #2,217,780.

is then taken between the two resistivity values for each position of the potential electrodes. This provides data for a resistivity increment

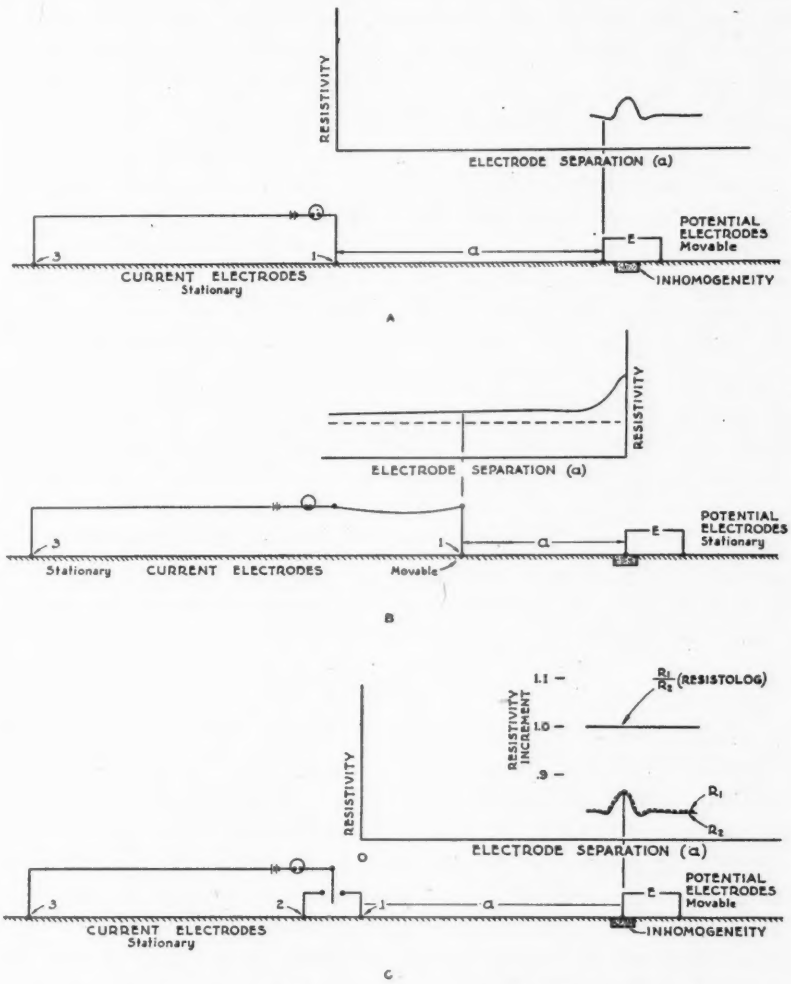


FIG. 2. Illustration of the incremental resistivity (*Resistolog*) method employed to eliminate the effect of superficial inhomogeneities.

curve R_1/R_2, which is approximately independent of shallow inhomogeneities along the potential electrode traverse. This curve will not, however, be independent of subsurface inhomogeneities below elec-

trodes *1* and *2* since such inhomogeneities will produce an influence on the apparent resistivity curve which varies with electrode separation. Resistivity increment curve R_1/R_2 thus indicates the rate of variation of apparent resistivity with electrode separation and will therefore have maxima or minima corresponding to apparent resistivity curve inflection points. Inhomogeneities in the immediate vicinity of *1* which differ from those in the vicinity of *2* will alter the resistivity increment curve, but the resulting deformation will be that of introducing a smooth curve similar to that of *B* in Fig. 2, which is approximately a straight horizontal line for large electrode separation. Obviously, adding such a curve to the resistivity increment curve will not alter the electrode separation at which maxima or minima occur, nor the relative magnitude of such features. For uniform conditions in the vicinity of *1* and *2* the resistivity increment curve R_1/R_2 will become unity at the point the apparent resistivity curve has a maximum or minimum, will be less than unity if apparent resistivity values are increasing with electrode separation, and greater than unity if these values are decreasing. Interpretation of resistivity increment curves is based entirely on resistivity increment curve maxima and minima, as described above. These extrema are independent of inhomogeneities in the vicinity of both current and potential electrodes. For convenience in description apparent resistivity increment curves obtained in the above manner have been named *Resistologs*.

SHALLOW RESISTIVITY DATA

Application of this procedure to relatively shallow prospecting is illustrated by Fig. 3. These data were obtained in the Horse Cave Area of Hart County, Kentucky. Except for a surface layer of soil which varied from 0′ to 10′ in thickness, the underlying beds were predominantly high resistive limestones to a depth of at least two thousand feet. Electrode *3* was placed on the same side of *1* and *2* as the potential electrodes but was about twice as far from the potential electrodes as 1 and 2. Curve R_1 is the apparent resistivity curve obtained with current flow between electrodes *1* and *3* and R_2 is a similar curve for flow of current between *2* and *3*, except that the apparent resistivity values for R_2 are plotted against the electrode separation *a* rather than the distance from potential to current electrode. Because curves R_1 and R_2 are practically coincident, curve R_2 has been offset by 20 ohms to facilitate comparison as to form. The two resistivity values plotted against each value of *a* are therefore the two resistivity values

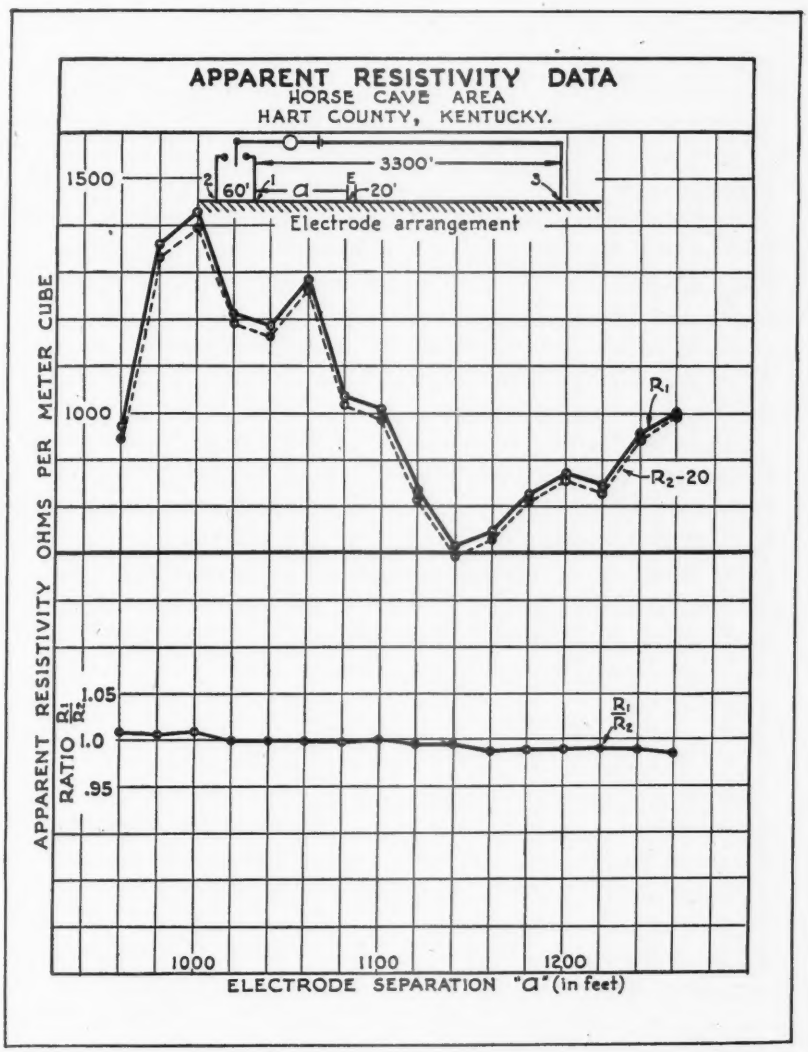


FIG. 3. Example from the Horse Cave area of Hart County, Kentucky, showing the elimination of the surface effects in the apparent resistivity by use of the resistivity increment. The apparent resistivity curve R_2 has been shifted down 20 ohms to facilitate comparison.

for each position of the potential electrodes. It is obvious that the various maxima and minima of these two individual apparent resistivity curves occur at a given position of the potential electrodes rather than at a given separation between potential and current electrodes and are therefore a result of shallow inhomogeneities along the potential electrode traverse. This conclusion is further supported by the resistivity increment curve (Resistolog) R_1/R_2, which was obtained by plotting the ratio between each of the two apparent resistivity values, as functions of a. Since each point on this curve is the ratio between two resistivity values which differ in separation between potential and current electrodes by 60 feet, any of the sharp maxima or minima of R_1 and R_2 occuring at a given separation between current and potential electrodes (i.e. due to subsurface beds) would have produced a similarly sharp change in R_1/R_2.

Apparent resistivity curve maxima and minima such as those of R_1 and R_2 have been frequently attributed to horizontal subsurface beds by previous investigators. Use of a greater separation between potential electrodes would, of course, tend to decrease the relative magnitude of the effect of these inhomogeneities. However, variation in apparent resistivity values by 20% along a potential electrode traverse 600 feet long because of shallow inhomogeneities is quite common even under favorable conditions.

MEASUREMENT PROCEDURE AND ELECTRODE ARRANGEMENT FOR DEEP PROSPECTING

In the application of the above procedure to deeper prospecting the electrode arrangement shown in Fig. 4 has usually been employed. As illustrated the separation between potential electrodes and between electrodes *1* and *2* is 600 feet. The distance between electrodes *2* and *3* is usually equal to or greater than the maximum depth to which prospecting is desired. The position of *3* is not critical. It is usually placed approximately collinear with *1* and *2* but various other positions, such as at right angles to the line of *1* and *2* or on the opposite side of the potential electrodes from *1* and *2*, such as in Fig. 3, have been employed. A practical difficulty as to the position of *3* is that it is difficult to maintain the degree of insulation necessary for precise work if the connecting current carrying line passes within 1000′ to 1500′ of the potential electrodes. The separation between potential electrodes is maintained constant for a given station. As previously described, electrode separation is varied by moving the potential electrodes, all

current electrodes remaining stationary for a given station. On initial attempts to apply this procedure to deep prospecting the distance between potential electrodes and electrodes *1* and *2* was varied by increments of 300 feet to 600 feet on the assumption that deep subsurface formations would produce rather broad maxima and minima. Discovery that features actually obtained in the field were larger and sharper than originally assumed to be likely led to variation of electrode separation by smaller and smaller increments, the various increments being a result of successively dividing 600 by 2. The pres-

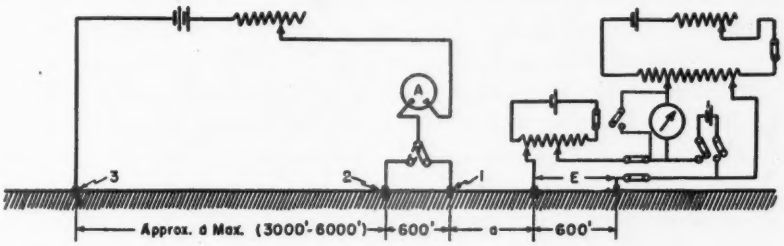


FIG. 4. Schematic diagram of the circuit employed, showing also the electrode separations used for relatively deep prospecting.

ent practice is to use an increment of $37\frac{1}{2}$ feet, although it is possible to obtain additional detail by use of an increment of $18\frac{3}{4}$ feet as indicated by the Resistologs of Figs. 14 and 18.

It is apparent that the resistolog procedure minimizes errors introduced by line leakage and instrument calibration since most errors of this type will similarly effect the two resistivities between which a ratio is taken. To minimize the effect of variation of instrument calibration while observations are in progress the various potential difference values which are taken for each position of the potential electrodes are alternated. The resulting two groups of potential values are then separately averaged for obtaining the two potential difference values which are used for calculation of the resistivity increment value.

A rather detailed description of the procedure employed for potential difference measurement will be given. This procedure is apparently critical for successful prospecting. Although the operation is quite tedious and requires considerable training in this particular type of measurement, skillful operation results in a precision of measurement which appears to be somewhat greater than otherwise attainable in the presence of ordinary earth current fluctuations.

Relatively small errors in measurement of potential difference may result in resistivity increment curves which do not positively correlate. A considerably higher degree of accuracy must therefore be maintained than ordinarily justified, or secured, in electrical prospecting.

Care must be exercised in laying out traverses in the presence of artificial conductors, particularly those extending from the vicinity of potential electrodes to the vicinity of the current electrodes. Wire fences, even where no connection with the earth exists, except through wooden posts, constitute the most troublesome source of error of this type, since errors of the same order of magnitude as anomalies due to subsurface features may result. In all cases in which wire fences cross or parallel the potential electrode traverse insulators are inserted in each wire on both sides of this traverse unless gates or other breaks in continuity of the wire exist nearby. Where such insulation is impossible traverses are laid out in another direction. As previously discussed, however, the magnitude of errors resulting from artificial conductors is greatly reduced with the Resistolog procedure relative to that obtained with usual electrical prospecting methods.

At least ten separate measurements of potential difference are made for each position of the potential electrodes, that is, five for current flow between electrodes 1 and 3 and five for current flow between 2 and 3. At least two independent sets of data are taken for each station, sets of data referring to two independent series of potential electrode positions. The usual practice is to first take data for obtaining an increment curve covering the desired range of movement of potential electrodes, and then to repeat these measurements one or more times depending upon the amount of discrepancy between the various sets of resistivity increment values. When sufficient data for at least two independent Resistologs, which check generally, are obtained, all data are averaged for the final curve.

Potential difference measurements are made by the null method, utilizing a potentiometer having a slide wire by which potential difference is varied by steps of one microvolt, and a total potentiometer range of 16 millivolts. A high sensitivity D'Arsonval type galvenometer having a voltage sensitivity of about 0.05 microvolt per millimeter deflection on a scale at one meter is employed for balancing the potentiometer. The usual type of porous pot non-polarizable electrode is used, the resistance between these electrodes usually being about 500 or 600 ohms. The galvanometer is therefore highly damped and

not responsive to rapid earth current fluctuations, since its critical damping resistance is 2400 ohms. A relay arrangement is provided by means of which the observer measuring potential difference can switch current to electrodes *1* and *3* (or *2* and *3*) on and off by remote control, thereby enabling the truck containing potential difference equipment to be stationed near the potential electrodes and the truck containing current equipment near electrodes *1* and *2*. This separation of current and potential difference equipment eliminates errors due to leakage between them or between current-carrying lines and potential equipment.

Observation of potential difference is made by simultaneously switching, on and off, potentiometer working current and the current to the earth, and adjusting the potentiometer until the deflection of the galvanometer is not altered by this switching. Deflection of the galvanometer during this switching operation is arrested by short-circuiting the coil. It is, of course, necessary to provide an auxiliary source of potential difference in the galvanometer-potential electrode circuit to compensate for potential differences existing between these electrodes when there is no flow of current between electrodes *1* and *3* or *2* and *3*. This procedure permits very precise measurement of potential difference in the presence of ordinary earth current fluctuations without the use of commutating devices, although the measurement is actually made during short quiet periods which usually occur. Fig. 4 shows a schematic diagram of the circuit employed.

Observation of the galvanometer is approximately during the period of time between five and ten seconds after the circuit to the current electrodes is closed. The current flow is manually adjusted to a given value by means of a rheostat during the entire period of flow. The same current value is usually maintained for flow to each current electrode and for all positions of the potential electrodes throughout a given set of data. The source of current is storage batteries, the resultant non-fluctuating applied E.M.F. permitting a precise adjustment of current flow. Magnitude of current flow is usually between 4 and 10 amperes for relatively deep prospecting in low resistive beds.

By means of the above described procedure, five potential difference values can practically always be obtained at a given potential electrode position which have a difference between the highest and lowest value not exceeding 5 microvolts. The overall accuracy of measurement of resistivity increment values attained in routine

prospecting has been such that an increment curve at a given station could be duplicated as to form within one quarter of one per cent (.25%) by an independent check.

An average of about thirty minutes time is required for an experienced operator to obtain one set of data for a given potential electrode position. Since at least two such sets of data are taken at least one hour is required to take data for each point on Resistologs. If potential electrodes are moved by the usual increment of $37\frac{1}{2}$ feet about 15 hours are required to cover a depth interval of 500 feet, exclusive of the time required for surveying, laying lines, etc.

The distance between electrodes *1* and *2* and distances to potential electrodes are measured along a surveyed line by means of a surveyor's chain, measurement being made along the horizontal. An

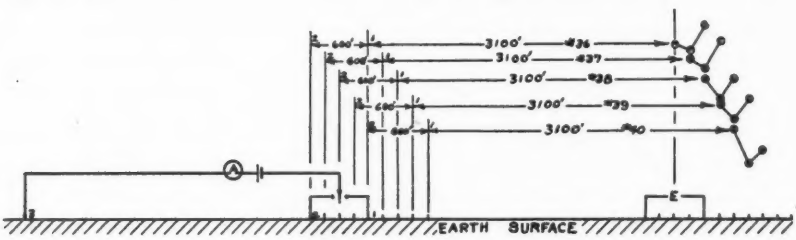


FIG. 5. System of overlapping potential electrode traverses which demonstrate that Resistolog features are not due to superficial inhomogeneities at the potential electrodes. Data from stations 36–40, Fig. 14.

independent check was usually made of these measurements. Electrode 3 is usually located approximately by compass and automobile speedometer.

The average of the elevation of electrodes *1* and *2* is used in all cases for designating the elevation of the station. The location of the station is designated as the midpoint of the line joining electrodes *1* and *2*, the location of the subsurface area prospected having been experimentally established as lying below this point by tests which will be subsequently described.

A number of rather simple but positive tests may be applied under field conditions for proving whether features on Resistologs are of subsurface origin.

The most positive test of this type is that illustrated by Fig. 5. In this case potential electrodes were moved by increments of 150 feet. By taking a series of stations along a given line at 150 foot inter-

vals (i.e., electrodes *1* and *2* both moved 150 feet) a series of Resistologs were obtained for which two of the potential electrode positions were identical with two of the potential electrode positions of the preceding station. However, the separation between potential and current electrodes for each of these two potential electrode positions differed by 150 feet. Any residual influence from shallow inhomogeneities which might be present would result in features which occurred at a given *potential electrode position*, while any feature resulting from horizontal subsurface beds would consistently occur at a given *electrode separation*. It will be noted that the Resistolog feature shown consistently occurred at the same separation between current and potential electrodes. The Resistolog feature shown in this case appears very pronounced because of the large scale to which the increment value is plotted. Such features would probably not be recognized even in the absence of shallow inhomogeneities with the accuracy of measurement ordinarily attained in electrical prospecting.

Another rather positive test of validity of data under field conditions can be obtained by rotating the electrode system about the midpoint of the line joining electrodes *1* and *2* so as to obtain two or more independent Resistologs at the same station. As will be subsequently demonstrated the point midway between 1 and 2 overlies the subsurface area prospected. By turning the electrode system about this point any desired number of Resistologs can be obtained at a given station, in which all potential electrode traverses differ.

Fig. 6 shows results of rotation of the electrode system sufficiently to place the potential electrode traverses 330 feet apart. Both resistivity and resistivity increment curves are shown in this case, this station being number 38 of Fig. 14. Although the corresponding apparent resistivity curves obviously do not have definite similarity, the Resistologs are quite similar.

Fig. 7 shows a case in which results were verified by rotating the electrode system through 90 degrees, the position of electrode *3* remaining stationary. The various sets of independent data which were averaged for obtaining the average, or final, Resistolog for each position of the electrodes, are shown. These two Resistologs are obviously similar as to features. The difference in slope probably results principally because electrode *3* was assumed to be at an infinite distance in making resistivity calculations. These curves are shown as computed and without rotation to the parallel position. The care necessary for obtaining data of the required accuracy under field conditions is indicated by the fact that over 350 independent measurements of poten-

tial difference were employed in calculating the above two Resistologs, approximately 36 hours having been required for making these measurements.

Fig. 8 shows experimental verification of the subsurface origin of features by rotating the electrode system through 180 degrees. This illustration shows the electrode arrangement employed, the various

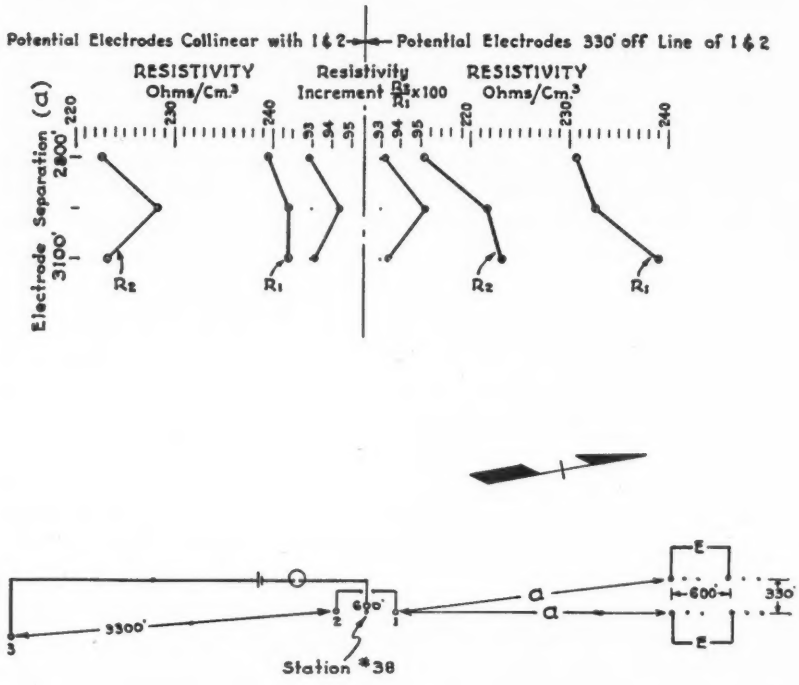


FIG. 6. Repetition of Resistolog features when potential electrodes are offset 330 feet, also illustrating the effect of surface inhomogeneities on apparent resistivity observations. Data at station #38 of Fig. 14.

sets of data which were averaged for obtaining the required accuracy of measurement, and curves indicating the accuracy of measurement.

The average position of the potential electrodes with these electrodes southeast of the station of Fig. 8 was approximately 10,000 feet from the average position of these electrodes when northwest of the station. The Pettus sand is estimated from a subsurface map of the area to be approximately 300 feet deeper under the potential electrodes when to the southeast of the station than when to the

northwest, and 150 feet deeper below the point halfway between current electrodes *1* and *2* than for the former position of potential electrodes. Since the two Resistologs obtained with the potential electrodes in these positions definitely correlate at the same electrode

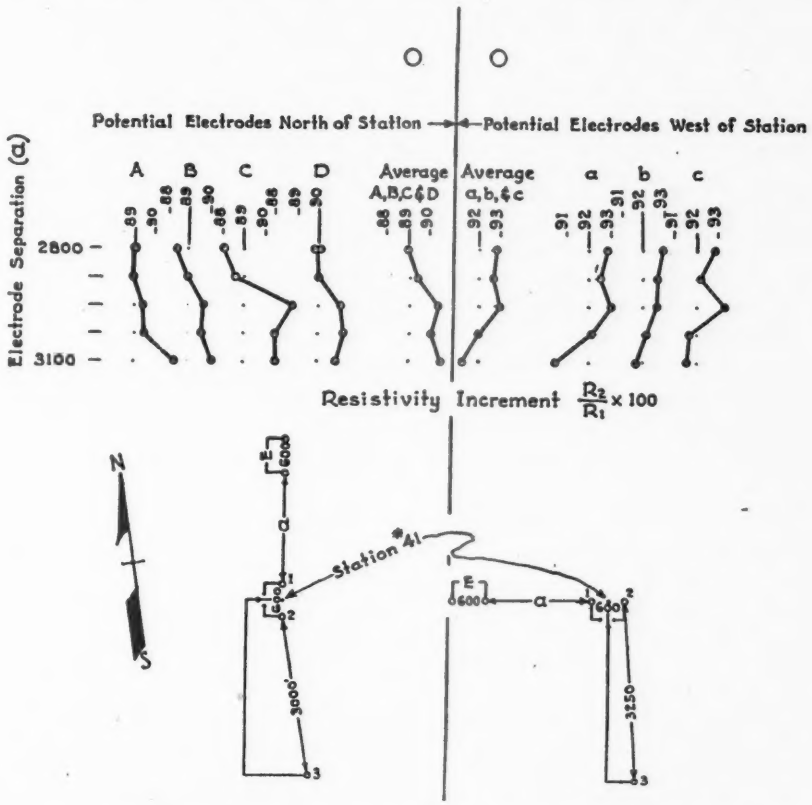


FIG. 7. Repetition of Resistolog features when the electrode system (except the electrode at "infinity," No. 3) is rotated 90° about a point midway between current electrodes 1 and 2. Data at station 41, Fig. 14.

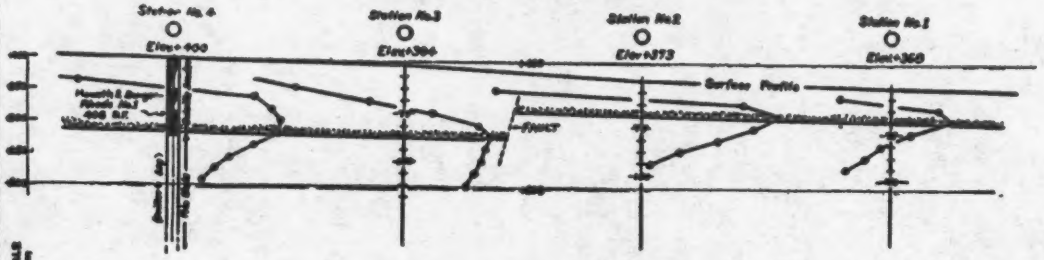
separation, it is evident that the subsurface area prospected in this case at least approximately underlies electrodes *1* and *2*. More positive tests for determining the subsurface area prospected will be discussed later. The definite similarity of the above two independent Resistologs at station 2 is also rather positive proof that these features are not a result of inhomogeneities along the potential electrode traverse. So accu-

RESISTOLOG SECTIONS

RHODE RANCH AREA
MCMULLEN COUNTY, TEXAS.

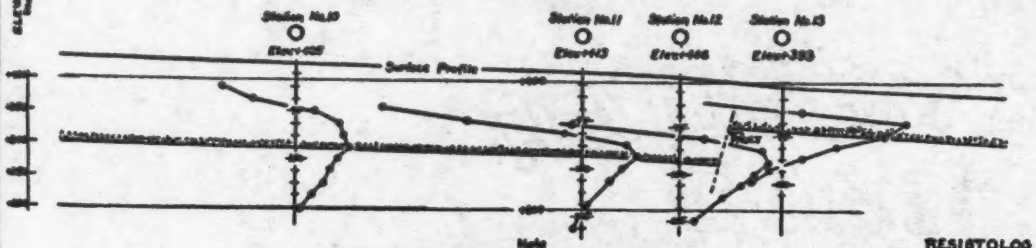
SECTION NO.1

N60°E Through Howeth & Geiger-Rhode No.1.



SECTION NO.2

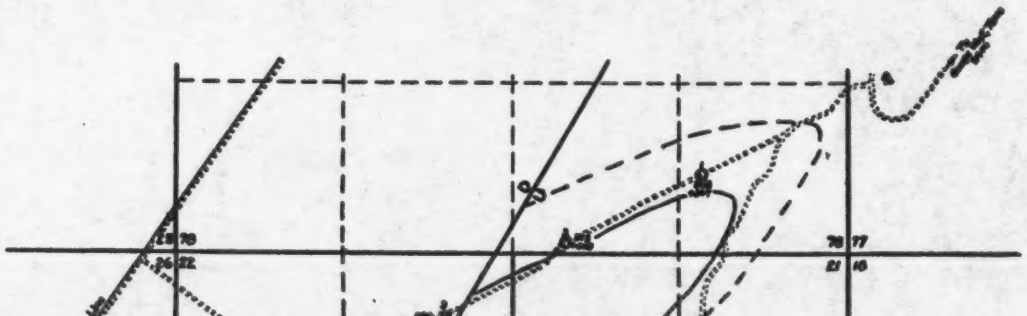
West-East in Vicinity of Howeth & Geiger-Rhode No.1



ELEVATIONS SCALE
One Inch Equals 100 Feet

Note
Electrode Spacing Increments = 10 Feet or a Multiple Thereof
Increment Scale Shown on Vertical Station Lines

RESISTOLOG SCALE
|-10/--|



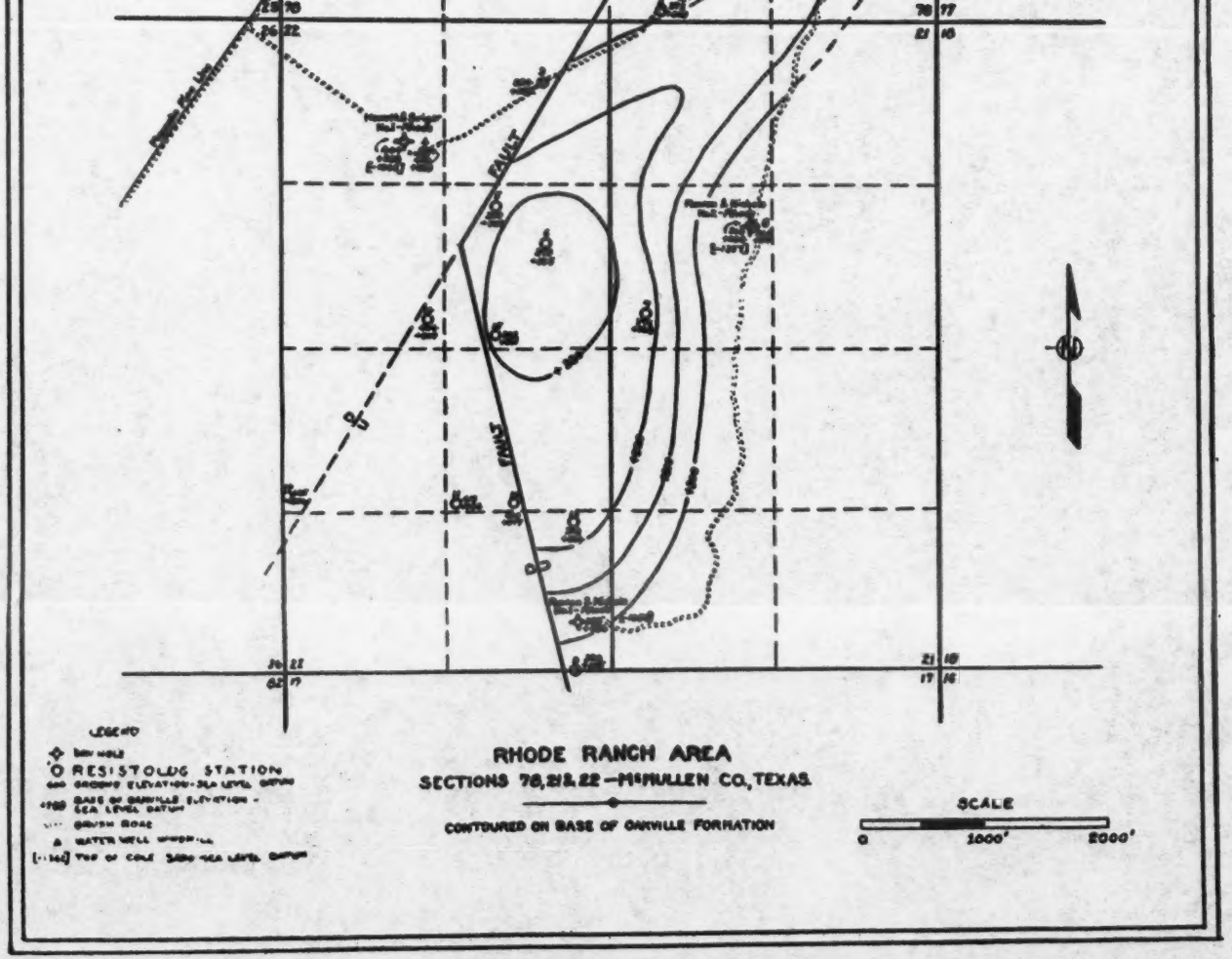


FIG. 9. Illustrating an application of the Resistolog procedure to shallow structural mapping, Rhode Ranch, McMullen County, Texas.

type of prospecting shows the various characteristics usually regarded as typical of resistivity prospecting. The features shown on the Resistologs are very large in comparison to those obtained in deep prospecting. It will be noted that the correlations check the variation in depth to the base of the Oakville sand at the three wells in the area within the limits of detail of Resistologs, or $18\frac{3}{4}$ feet. Results in other areas, however, indicate that cutting out of high or low resistive members produce a variation in the relation between depth of prospecting and electrode separation in such shallow prospecting. It is nevertheless possible to reliably detect abrupt changes in depth such as that produced by a fault with considerable accuracy, if stations are sufficiently close together. Faults result in abrupt changes in indicated depth from one value to another, whereas stratigraphic changes usually result in a progressive variation of indicated depth, several intermediate values being obtained between the two extremes. As will be subsequently indicated by field results, variation in relation between electrode separation and depth of prospecting is much less prevalent in deep prospecting and is probably of a different nature than that encountered as shallow depths.

STRUCTURAL SURVEYS

Branyon Field, Caldwell County, Texas

Fig. 10 shows a traverse across a known fault in the Branyon Field of Caldwell County, Texas. The purpose of this survey was the determination of the accuracy with which the Austin Chalk trace of a fault could be located. After locating the point along the traverse at which this fault was indicated by Resistolog correlations the electrode system was rotated through 180° about the point halfway between electrodes *1* and *2*, and Resistologs at stations 6 and 7 verified, these being the stations between which the subsurface trace of the fault was indicated. Resistologs obtained with potential electrodes both East and West of the station (point half way between *1* and *2*) are shown in Fig. 10 with those obtained with the potential electrodes to the West of the station plotted deeper to avoid the confusion of overlapping; the features shown actually occurred at the same electrode separation as those from the potential electrodes East of the station. Since electric logs and straight hole surveys were not made on wells from which the subsurface trace of this fault was determined, the location indicated by Resistolog data appears to be within the limits of ac-

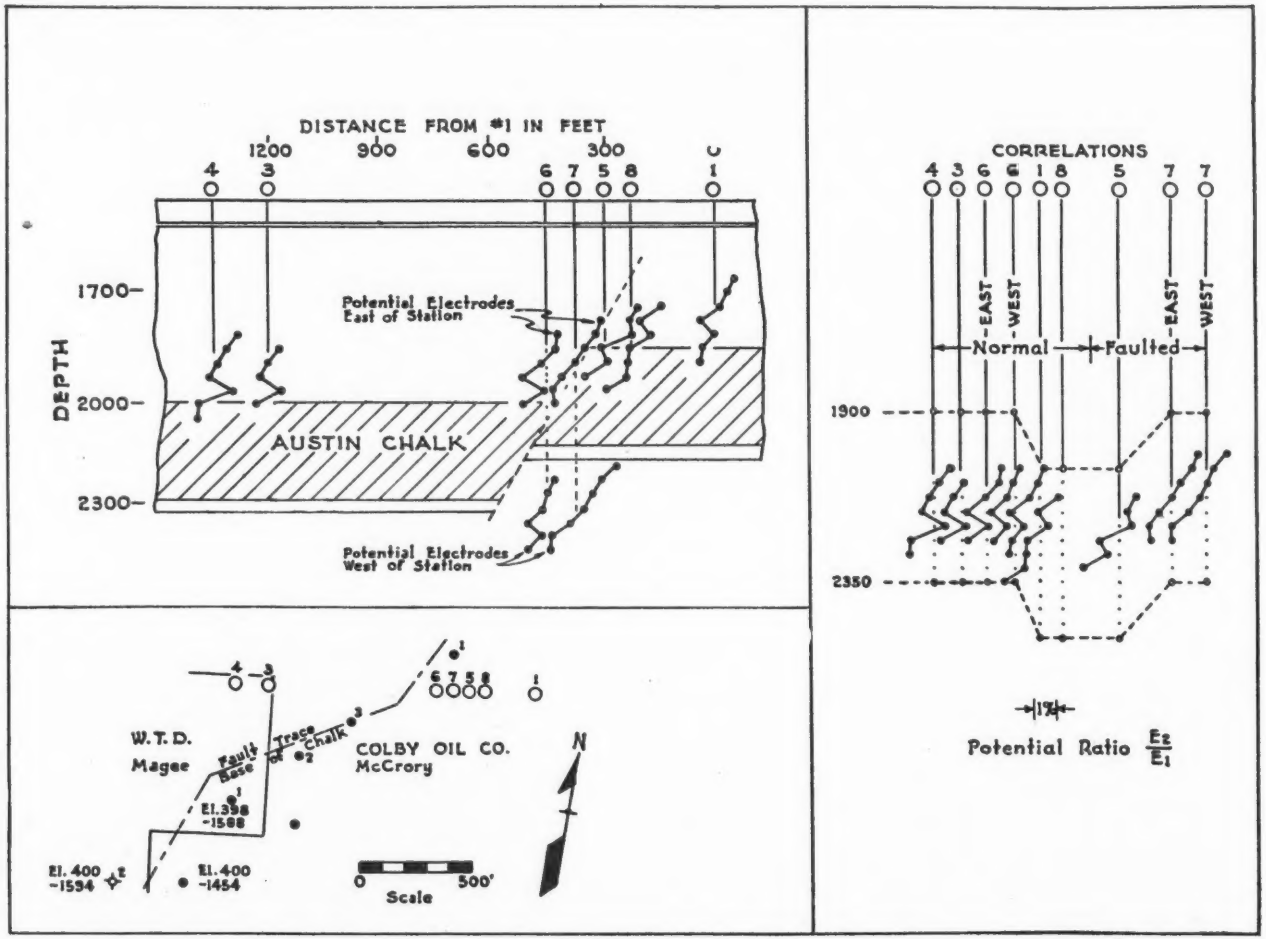


FIG. 10. Location of the known subsurface trace of a fault, indicating, by the identity of Resistologs made by rotation of the electrode system through 180° about the point midway between current electrodes 1 and 2, that the area prospected is below this point.

curacy with which it was determined by drilling. Resistolog correlations check the displacement of this fault in direction and to within 10 feet in magnitude. Verification as to the subsurface origin of the features in this area, in addition to that obtained by rotation of the electrode system, is supplied by Resistologs at stations 6 and 7 with potential electrodes to the East. The deeper five points of the Resistolog at station 6 were obtained with the potential electrodes in identically the same series of positions as were the five shallowest points of station 7, the only change in electrode position being that electrodes *1* and *2* were 75 feet further West for station 6 than for station 7. It will be noted that the feature at the lower end of the Resistolog at station 6 corresponds to a smooth curve at station 7. Furthermore, the validity of Resistologs at both stations 6 and 7 was proved by duplication of these Resistologs with the electrode system rotated through 180° about the point halfway between electrodes *1* and *2*.

A fault located by a similar traverse about one half mile west of the above was established by subsequent drilling to have an Austin chalk trace at least within 150 feet of that indicated by Resistolog correlations, while the magnitude of displacement was within 10 feet of the indicated value.

The separation employed between electrodes *1* and *2* and between potential electrodes in this area was 300 feet.

Dunlap Area, Guadalupe County, Texas

Fig. 11 shows results along a traverse which was made for more accurately locating a fault, the position of which was approximately known from subsurface data. Oil production is obtained in this area from the Austin chalk, when this formation has sufficient permeability and porosity. Development in the area indicated that these required conditions were practically always present in or immediately adjacent to fault planes. Locations for D. G. Herring #1 and #2 Frank Appling and #1 C. F. Appling were made on the basis of the above survey. These wells encountered permeability and porosity in the Austin Chalk and were completed as oil wells. #2 Frank Appling encountered the top of the Austin Chalk 29 feet and 40 feet lower than did #1 Frank Appling and #1 C. F. Appling, respectively, apparently verifying the 35 foot fault indicated by Resistolog correlations. The existence of this fault had not been established by subsurface data prior to the Resistolog survey. The position of the second fault, having a displacement of 108 feet according to Resistolog correlations, has not

trode system through 180° about the point midway between current electrodes 1 and 2, that the area prospected is below this point.

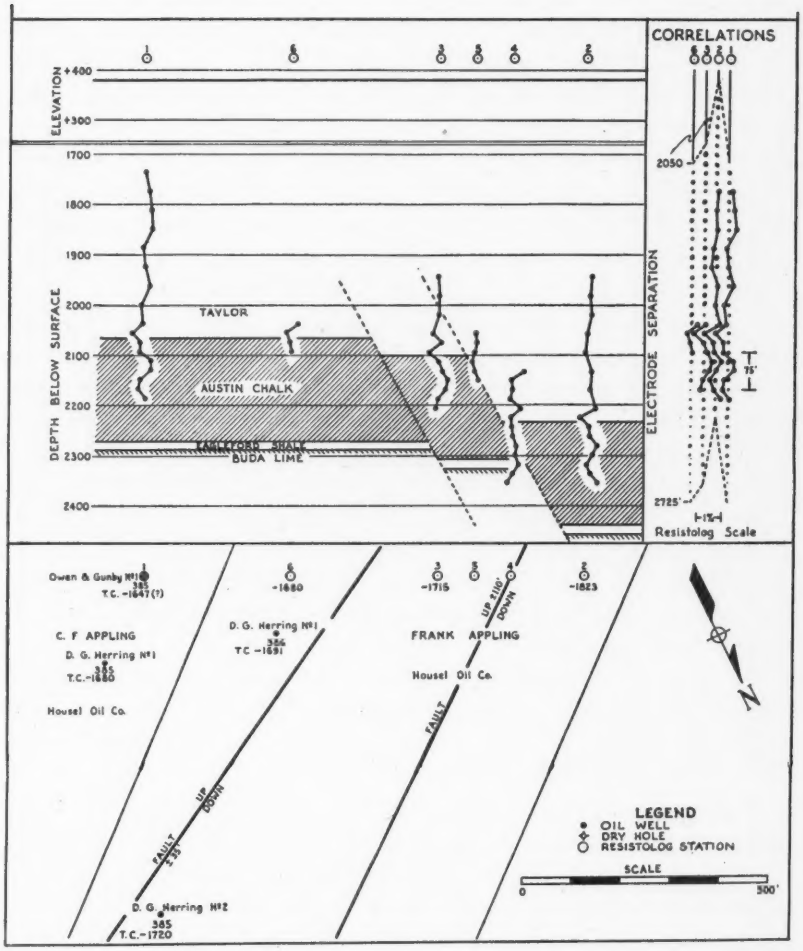


FIG. 11. Location of the Austin Chalk trace of a fault in the Dunlap area of Guadalupe County, Texas, by correlation of Resistologs.

been accurately located by drilling, although, as previously stated, its existence in the approximate vicinity is indicated by subsurface data.

It will be noted by reference to the Resistolog scale in Fig. 11 that features on which correlations are based are relatively small. Correlations appear to be positive, however. It is also of interest to note that Resistologs at stations 4 and 5 which cover the subsurface interval in which the fault plane occurs, according to correlation of

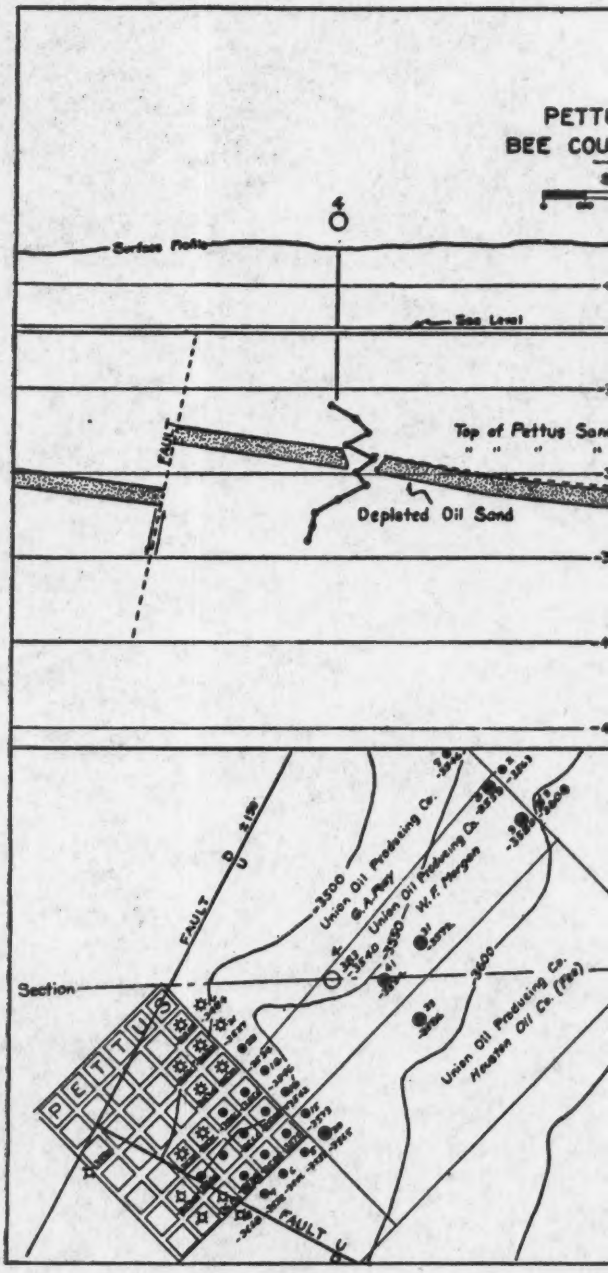
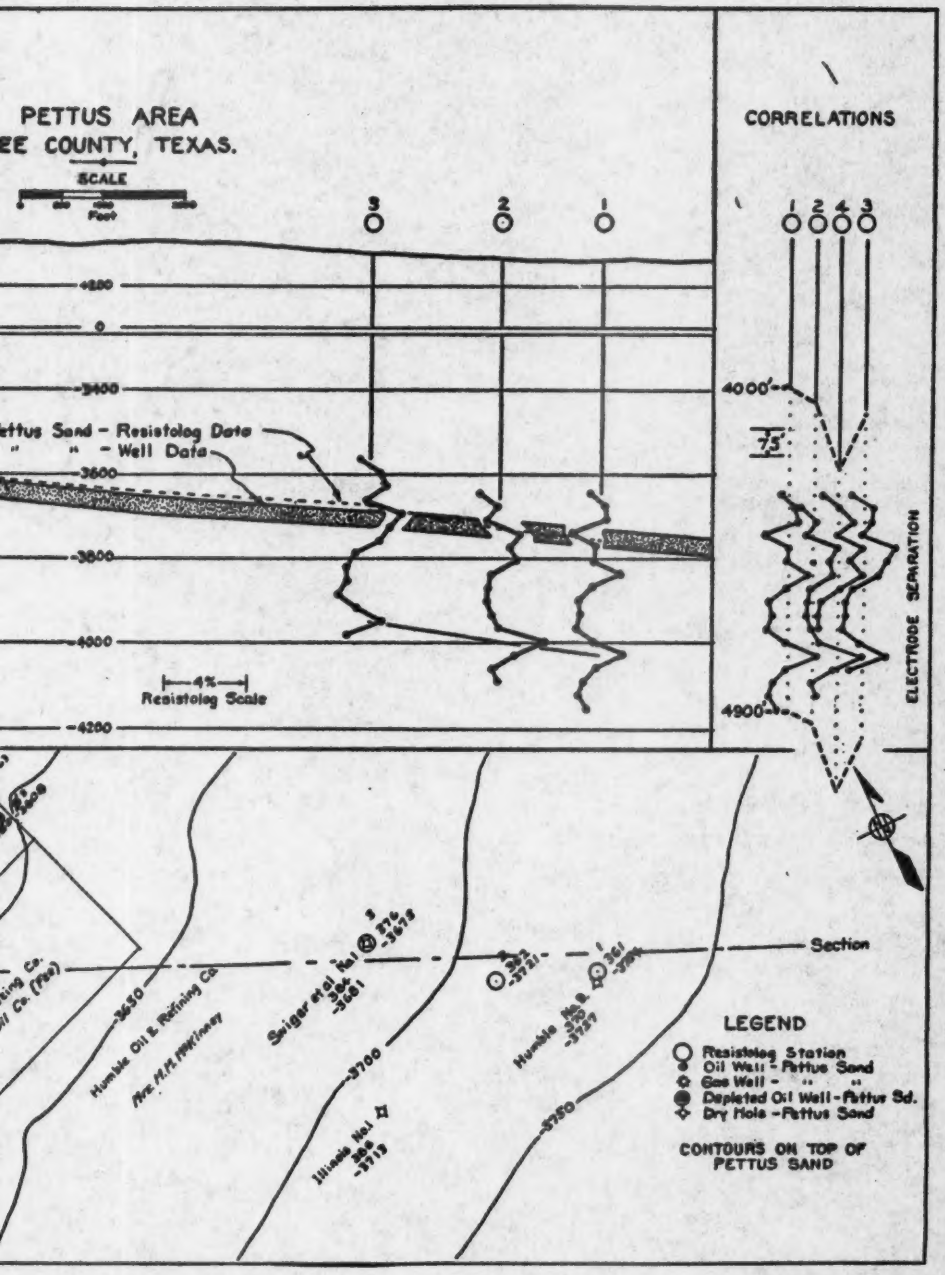


FIG. 12. Structural profile and contour map of the Pettus area of
the Pettus sand. 180° rotation



s area of Bee County, Texas, showing correlation of the portions of the Resistologs associated with
' rotation of electrode configuration at station 2 was shown in Fig. 8.

Resistologs at stations 2 and 3, are not similar to other Resistologs in the area. The separation employed between current electrodes *1* and *2* and between potential electrodes in this area was 300′.

Pettus Area, Bee County, Texas

Fig. 12 shows Resistologs along a traverse extending down dip from the Pettus field along the indicated line. Resistologs have been plotted against depth by use of a relation between depth and electrode separation to be shown in Fig. 18. The relation between depth of prospecting and electrode separation was not actually determined for this area, so it is not definitely known that the point on Resistologs correlated with the Pettus sand is actually that shown. Resistolog correlations conform to subsurface data, however. It is therefore obvious that Resistolog markers parallel and probably are near the Pettus sand.

Correlations employed in making this section are shown at the right of Fig. 12. The depth to the Pettus sand along this traverse ranged from 3900 feet to 4100 feet. The range through which the electrode separation a was varied was between 4000 feet and 4900 feet. The electrode arrangement was similar to that of Fig. 4.

Because of the unexpectedly large features obtained on these Resistologs unusual effort was made to prove positively that they were not a result of superficial effects or errors in measurement. From three to five days were devoted to taking data at each station. More than 750 independent measurements of potential difference were used in calculating Resistologs at each of stations 1 and 3, a total of more than 1500 values for the two stations. In case of each potential difference measurement the apparently correct potentiometer setting was checked some five or ten times for definitely determining that no discernible galvanometer deflection resulted, before recording the potential difference value.

The large Resistolog features and positive correlations obtained in this area have also been obtained on other surveys of similar depth, particularly along this trend. It is evident from reference to the electrical log of Humble Oil and Refining Co. #9 McKinney, on the section of Fig. 19, that the relatively large magnitude of these features is not explained by resistivity contrast as measured by electrical well logs. Experimental verification as to the subsurface origin of these relatively sharp features by rotating the electrode system about the point halfway between electrodes 1 and 2 has been shown by Fig. 8.

The obtaining of positively correlating Resistologs such as those of Fig. 12 also constitutes rather definite proof that features are of subsurface origin, this being particularily true if resulting correlations also indicate a variation in depth of subsurface beds conforming to that indicated by well data. Shallow inhomogeneities and errors of measurement, the only other likely source of such features, are random in nature, and would therefore practically never result in definite similarity, while both similarity and correlations conforming to variation in depth of subsurface beds would be still less likely to occur accidentally.

POSSIBILITY OF DIRECT DETECTION OF OIL AND GAS SATURATION—DISCUSSION

Incremental resistivity observations which evidently reflect variations of electrical properties of subsurface beds at interesting depths suggest the possibility of direct detection of oil and gas saturation. Due to the effects of shallow inhomogeneities it has heretofore been impossible to determine accurately by direct measurement whether oil or gas saturation at depths of practical importance could be detected by surface measurements. Williston and Nichols,[6] Lee and Swartz[7] and Karcher and McDermott[8] have described possibly successful efforts at the direct detection of oil and gas saturation by standard four electrode DC surface resistivity measurements. However, no means of correcting data for shallow inhomogeneities was employed in any of these cases. It follows that successful detection was possible only in those rare cases in which the anomaly resulting from oil or gas saturation was large in proportion to the influence of shallow inhomogeneities.

As has been frequently recognized, shallow inhomogeneities such as variation in moisture content of shallow beds, rock outcrops, gravel deposits, etc., introduce anomalies into the data of all basic electrical prospecting procedures. Such shallow inhomogeneities produce a wide variety of anomalies of various magnitudes and areal extents, which sometime appear to coincide with oil saturated areas either by chance or because of some influence of associated structural con-

[6] Williston and Nichols, *U. S. Patents #1,842,361, #1,841,376, #1,842,362, #1,841,-975, #1,841,976,* and personal communication.

[7] *U. S. Bureau of Mines Technical Publications #488* and *#521* and *U. S. Patent #1,951,760* to F. W. Lee.

[8] Karcher and McDermott. Bulletin of the A.A.P.G. Vol. 19, p. 64 (January 1935).

ditions on shallow beds. It is probable that at least some of these supposedly successful cases of direct detection were a result of coincidence of shallow inhomogeneities with oil ar gas saturated areas. It is likewise probable that failures in wildcat territory reported by Williston and Nichols[9] and Karcher and McDermott[10] were also a result of shallow inhomogeneities rather than the postulated variation of electrical properties of deep-lying beds. The latter conclusion is supported by electrical well logs. Although variations in thickness and resistivity of subsurface formations do occur, beds lying at the depths from which oil and gas are usually produced are ordinarily shown to be remarkably uniform laterally by electric logs. It is probable that electrical properties of such formations are at least no more erratic than are the physical characteristics upon which seismic and other prospecting procedures are based.

It may be proved both experimentally and theoretically that replacing all or a portion of the water which normally saturates a given specimen of sand with oil or gas always results in an increase in resistivity.[11] It is also established by electrical well logs, however, that formations which are not oil or gas saturated sometimes have a lateral variation of resistivity of the same order as that resulting from oil and gas saturation. This is no doubt true of any other physical characteristic which might be employed for the direct location of oil or gas saturation. The problem of direct location of oil or gas is therefore resolved into two steps: the measurement of the anomaly; and the distinction between anomalies resulting from oil or gas saturation and those due to other causes. However, field data which have previously been described, such as those of Fig. 3, in which the relatively large influence of shallow inhomogeneities is demonstrated, very strongly suggest that the failure to successfully apply electrical methods to direct location of oil has thus far been entirely because of failure to separately measure the anomaly. This results because of the predominating influence of shallow inhomogeneities rather than because of erratic variation in the resistivity of deeper subsurface beds.

Electrical well logs provide some information as to the accuracy with which resistivity may be employed for determination of oil or gas saturation. Resistivity as measured by electric logs is not, however, the true in-place resistivity, since invasion of water from the drilling

[9] *Loc. cit.*

[10] *Loc. cit.*

[11] Martin, Murray, and Gillingham, GEOPHYSICS, Vol. III, No. 3 (July 1938).

mud into permeable formations and the "shortcircuiting" effect of the drilling mud tend to decrease the apparent resistivity of oil sands more than that of other formations. This results in a reduction of resistivity contrast of oil sands as compared to adjacent beds. The accuracy of interpretation of electrical well logs is also a function of the number of logs available in the immediate vicinity for comparison. It is believed that if electric logs were available on a sufficient number of wells distributed over an oil productive area, including wells just off the saturated area in all directions, that a very high degree of accuracy of interpretation as to oil or gas saturation could be obtained solely on the basis of electric log data. With this quantity of data available it can be determined that: (1) an area of higher than normal resistivity exists in a particular horizon; (2) that this area has a down dip edge following a given structural contour; (3) and that geological conditions favorable for oil accumulation exist. With the possible exception of very shaly sands and of areas in which oil accumulation is controlled entirely by variation of porosity these data should be adequate to approximate positive determination of oil or gas saturation. The quantity of data necessary for such a scheme of interpretation is practically never available in the interpretation of electric logs. However, in the case of a surface geophysical method data at a large number of stations over the area under investigation can be employed for interpretation. It is thus evident that the accuracy of interpretation of such electrical prospecting data is primarily determined by the accuracy with which the variation of resistivity with depth can be measured. If an accuracy of measurement of variation of depth to a given bed and the lateral variation of resistivity within that bed approximating that of electric logs is attained a high degree of accuracy of interpretation in terms of oil and gas saturation and structure should be possible. So high a degree of accuracy of measurement is hardly to be expected in practice but it seems evident that no limitation of importance exists other than the difficulty of attaining a measurement which accurately indicates the variation of resistivity of subsurface beds with depth.

POSSIBILITY OF DIRECT DETECTION OF OIL AND GAS SATURATION—FIELD EVIDENCE

Seven Sisters Field, Duval County, Texas

Fig. 13 shows the results of an experimental survey made in an effort to make direct measurement of the anomaly resulting from oil

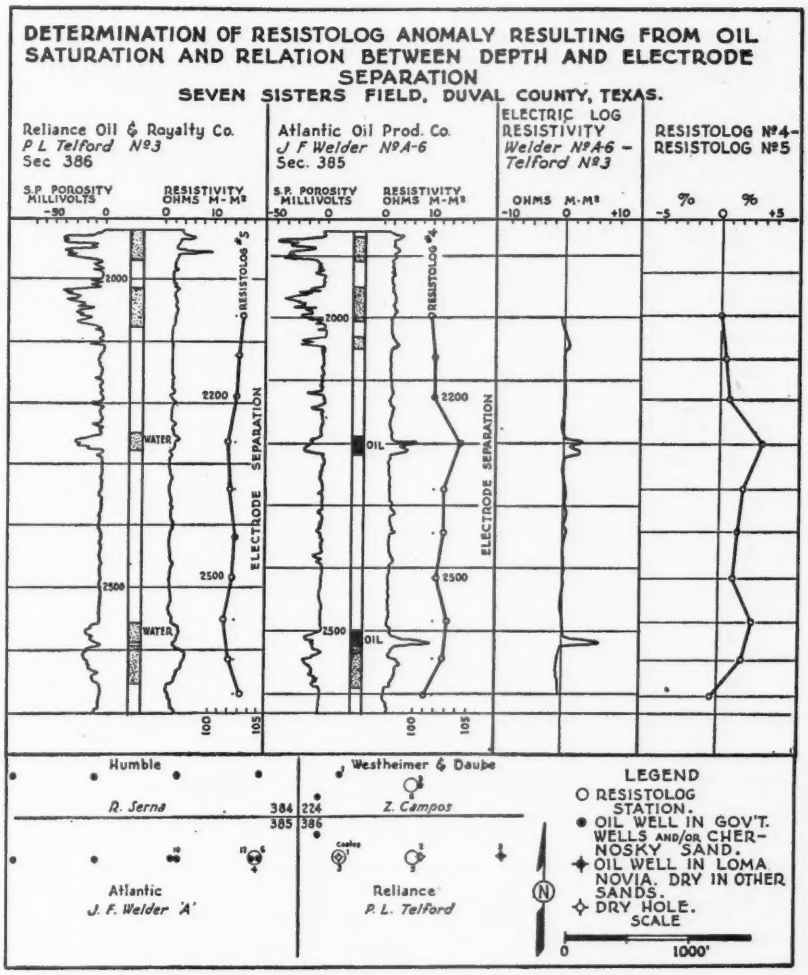


FIG. 13. Illustrating the change in electrical well log (next to last panel) and Resistolog (last panel) in passing from a well on the water side of the oil-water contact (Reliance Telford #3) to a well on the oil side (Atlantic Welder #A-6) in the Seven Sisters Field of Duval County, Texas.

saturation. This traverse was across the East edge of the Seven Sisters field of Duval County, Texas. In this case the water-oil contact in both the Government Wells and Chernosky sands occurs between the stations 4 and 5 for which Resistologs are shown. Both the Chernosky

sand at a depth of 2200 feet and the Government Wells sand at a depth of 2500 feet are oil saturated in Atlantic #A-6 Welder and water saturated in Reliance #3 Telford. The resistivity increment curves obtained in the vicinity of these wells are shown plotted against actual depth by use of the depth-electrode separation curve of Fig. 18. The difference between these two Resistologs is shown on the extreme right of Fig. 13 alongside the difference in electric log resistivity of the above wells. In this case it was not only necessary that two Resistolog maxima be present at the station over the oil saturated area which were absent off this area, but also for these features to occur at a difference in electrode separation corresponding to a difference in depth of 300 feet.

The apparent relation between Resistolog features and the occurrence of oil saturation was verified by other traverses in the Seven Sisters and the nearby Loma Alto fields.

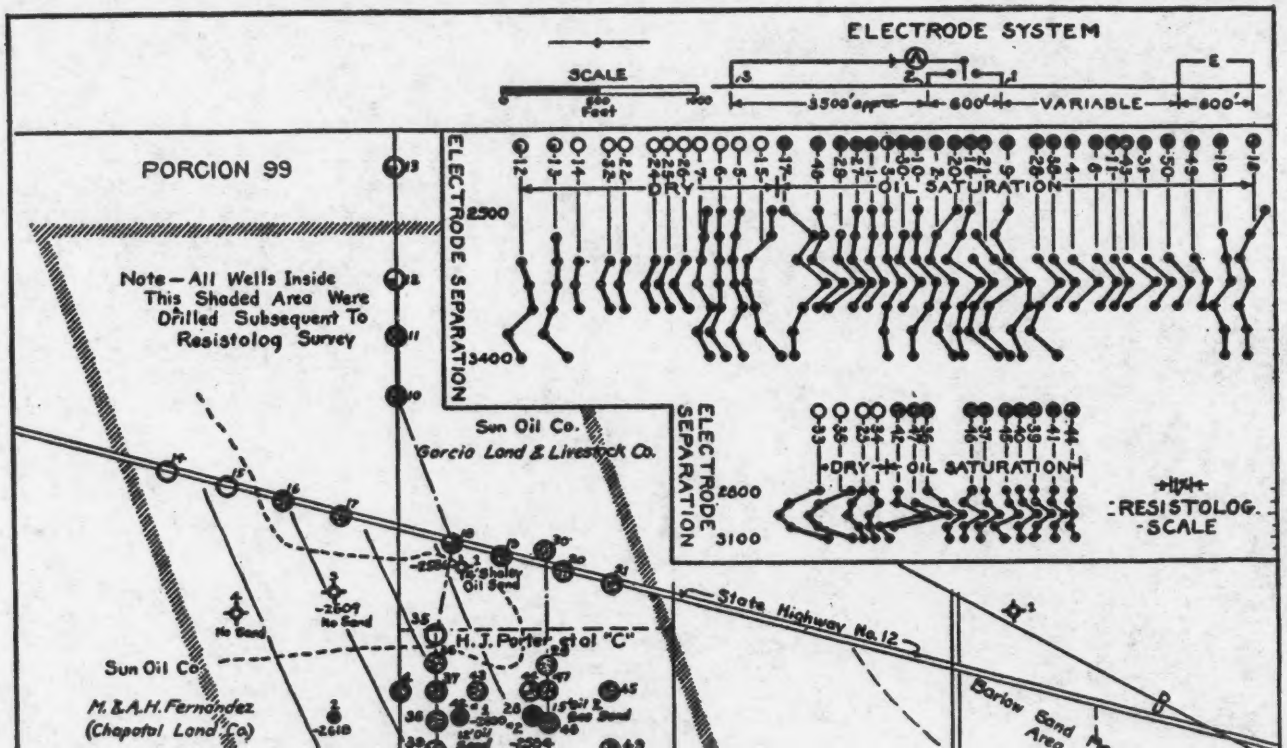
To determine whether results were influenced by well casings and pipe lines the north edge of oil saturation in the Government Wells sand in the Seven Sisters field was located in advance of development. Subsequent drilling established the edge of saturation to be between the two limiting stations at this point, these stations being 600 feet apart.

As indicated by the curve of Fig. 18 an oil sand at 2200 feet produced a Resistolog maximum at an electrode separation of 2275 feet, while an oil sand at a depth of 2500 feet produced a Resistolog Maximum at an electrode separation of 2575 feet. Electrode separation is, of course, the distance *a* of Fig. 4.

SamFordyce Field, Starr County, Texas

The application of the Resistolog procedure to the determination of the extent of an already discovered oil field is shown by Figs. 5, 6, 7, 14, 15, and 16. The area covered by this survey was the northwest end of the SamFordyce field of Starr and Hildago Counties, Texas, this survey having been confined to the Starr County portion as shown by the map of Fig. 14. The primary purpose was to determine the extent of the oil saturated area, in advance of development. In the area surveyed all oil and gas production is from the SamFordyce sand of the Frio formation, at a depth of 2800 feet. Deeper sands later proved productive on other portions of the SamFordyce structure but were not productive in the area under consideration.

At the time of the initiation of this survey Phillips and Barnsdall


ELECTRODE SYSTEM
SCALE
Feet
3500' approx
600'
VARIABLE
600'
PORCION 99
ELECTRODE SEPARATION
2500
3400
DRY
OIL SATURATION
Note — All Wells Inside This Shaded Area Were Drilled Subsequent To Resistolog Survey
Sun Oil Co.
Garcia Land & Livestock Co.
ELECTRODE SEPARATION
2600
3100
DRY
OIL SATURATION
RESISTOLOG. SCALE
State Highway No. 12
H. J. Porter et al "C"
Sun Oil Co.
M. & A. H. Fernandez (Chapotal Land Co.)
Barlow Sand Area

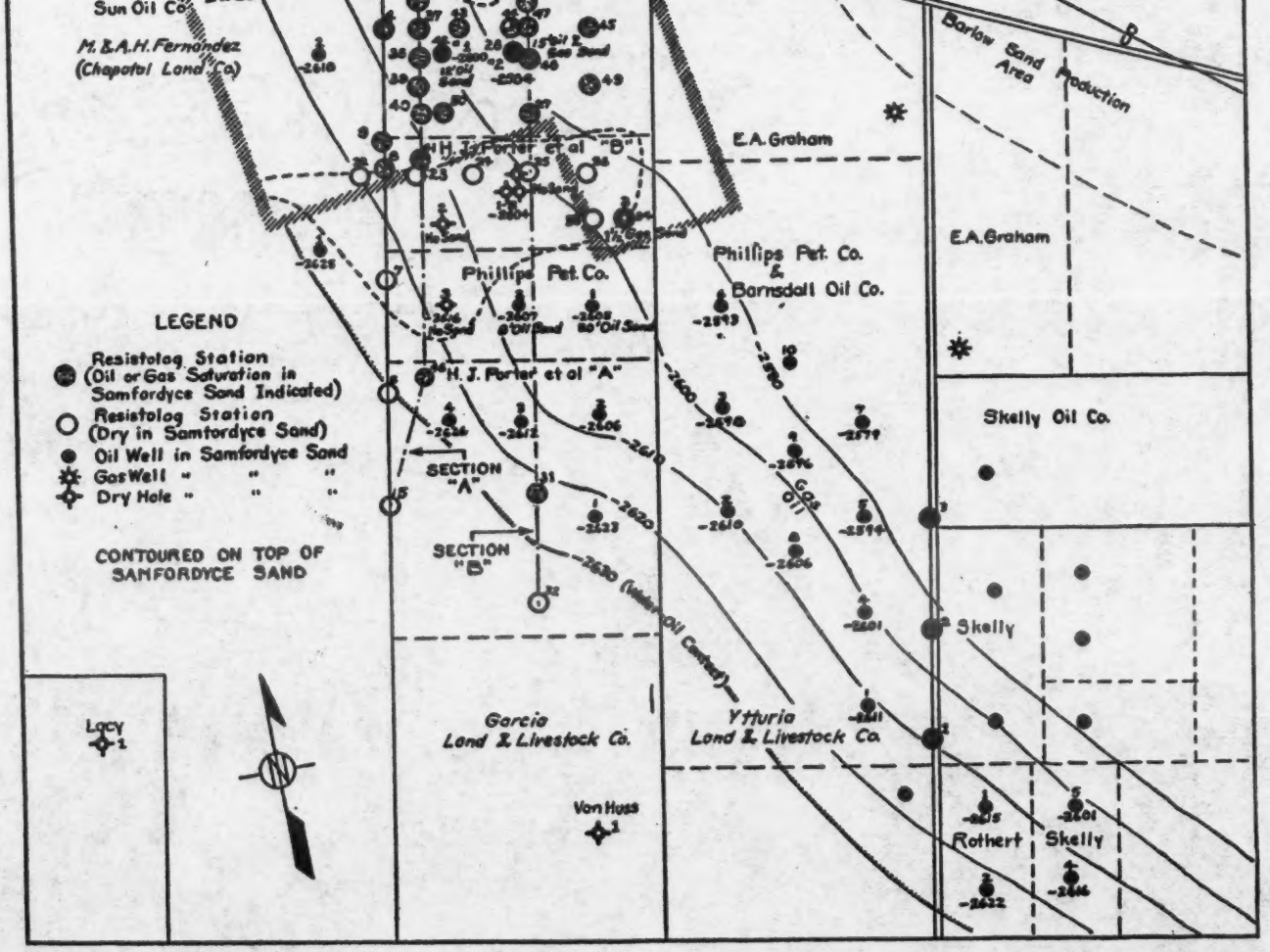


FIG. 14. Northwest end of the SamFordyce field of Starr County, Texas, showing location of wells, structural contours on the SamFordyce sand, location of Resistolog stations, and interpretation of Resistologs. The area surrounded by the hatchured boundary was developed after this survey was run.

ELECTRODE SYSTEM
SCALE
ELECTRODE SEPARATION
PORCION 39
Note — All Wells Inside This Shaded Area Will Be Offset Operated By Pressured Sinco
ELECTRODE SEPARATION
SERVICE RESISTANCE
Sun Oil Co
Phillips Pet Co
E A Graham

#1 Ytturia was the northwesternmost oil or gas well in the Sam-Fordyce field. Stations 1, 2, and 3 were taken over the known oil saturated area for comparison with similar data off this area, such as at stations 5 and 32. The various resistivity increment curves, or Resistologs, obtained in the area are shown in the upper right hand corner of Fig. 14. The scheme of plotting is such that the inflection point associated with a resistivity maximum produces a resistivity increment curve peak having an apex which points to the right. The upper group of curves are those on which electrode separation was varied by moving the potential electrodes by 150 foot increments. Potential electrodes were moved by 75 foot increments in the case of the lower group. The influence of oil or gas saturation is obvious from comparison of the various Resistologs over the oil saturated area with those off this area. It will be noted that these Resistologs may be divided into two well defined groups of definitely similar curves, those on the oil saturated area, and those off this area. These Resistologs are shown exactly as computed, except that each has been rotated to approximately the parallel position. Each Resistolog is the average of two or more independent Resistologs which were similar as to features. No adjustment of values or elimination of "bad" data has been employed.

A more quantitative determination of the net anomaly apparently resulting from oil saturation is shown on the right-hand side of Fig. 16. In this case a Resistolog over the oil saturated area (Station 17 on Highway 12) is subtracted from a Resistolog off this area (Station 15, 600 feet to the northwest.) It will be observed from these data that a Resistolog maximum is produced at an electrode separation a of 2950 feet by an oil sand at a depth of 2800 feet.

Resistologs covering sufficient range of electrode spacing show correlatable features which persist regardless of the presence or absence of the features attributed to oil or gas saturation. This fact is also illustrated by the Resistologs of Fig. 17. Except for short range curves for filling in details between control stations, the procedure in the Sam Fordyce field was first to correlate Resistologs with those at known points and then to note whether a maximum occurred at the point corresponding to the Sam Fordyce sand as determined by traverses across known edges of oil saturation in this formation. With this scheme of interpretation the location of a subsurface boundary in a given horizon is not necessarily based on the disappearance from the Resistolog of the maximum (or minimum) resulting from this hori-

zon. It is only necessary that the position of the Resistolog of this feature change relative to that of maxima or minima on which the correlation is based. It is believed that the very sharp determination of the edges of oil saturation in the Sam Fordyce area with this procedure is a result of such a shift in position on the Resistolog of the corresponding feature rather than to any abrupt decrease in magnitude of this feature. The depth to the SamFordyce sand was approximately the same throughout the area covered by this survey. This fact, along with the relatively large increment by which potential electrodes were moved, resulted in all Resistologs correlating at the same electrode separation.

Because of the apparent fidelity with which Resistologs delineated the known oil saturated area it was decided to take so great an amount of data of the maximum accuracy obtainable as to definitely preclude accidental agreement with subsurface conditions. With this in view over three months were devoted to taking date in the relatively small area covered by the map of Fig. 14. These data were also subjected to the various auxiliary tests of validity.

It will be noted by reference to Fig. 14 that interpretation as to oil or gas saturation on the above basis coincides with the known or subsequently determined oil productive area in considerable detail both on traverses across the oil-water contact and across edges of the saturated area in which the oil sand was replaced by shale.

The isolated oil productive area contained within the shaded area of Fig. 14 was discovered as a direct result of this survey. H. J. Porter et al. (Porter and Grimes) #1-C Garcia, the discovery well for this area, was an offset to two dry holes, Porter #1-B and #2-B Garcia, and was beyond the limits of the field as indicated by the then existing subsurface information.

The barren area in the vicinity of Porter #1-B and #2-B Garcia was indicated in advance of drilling by the Resistolog at station 7, and later detailed by additional stations. The barren area in the vicinity of Sun #3 and #4 Chapotal and #1 Garcia was also indicated in advance of drilling by stations 35, 18, and 44.

Sections A and B of Figs. 15 and 16 respectively are taken along the lines indicated on the map of Fig. 14. Sand thickness and saturation shown are as determined by drilling. In this case Resistologs are plotted against actual depth by the relation between depth of prospecting and electrode separation shown by Fig. 18. The latter curve was determined by traverses across known subsurface boundaries in areas of generally similar subsurface conditions.

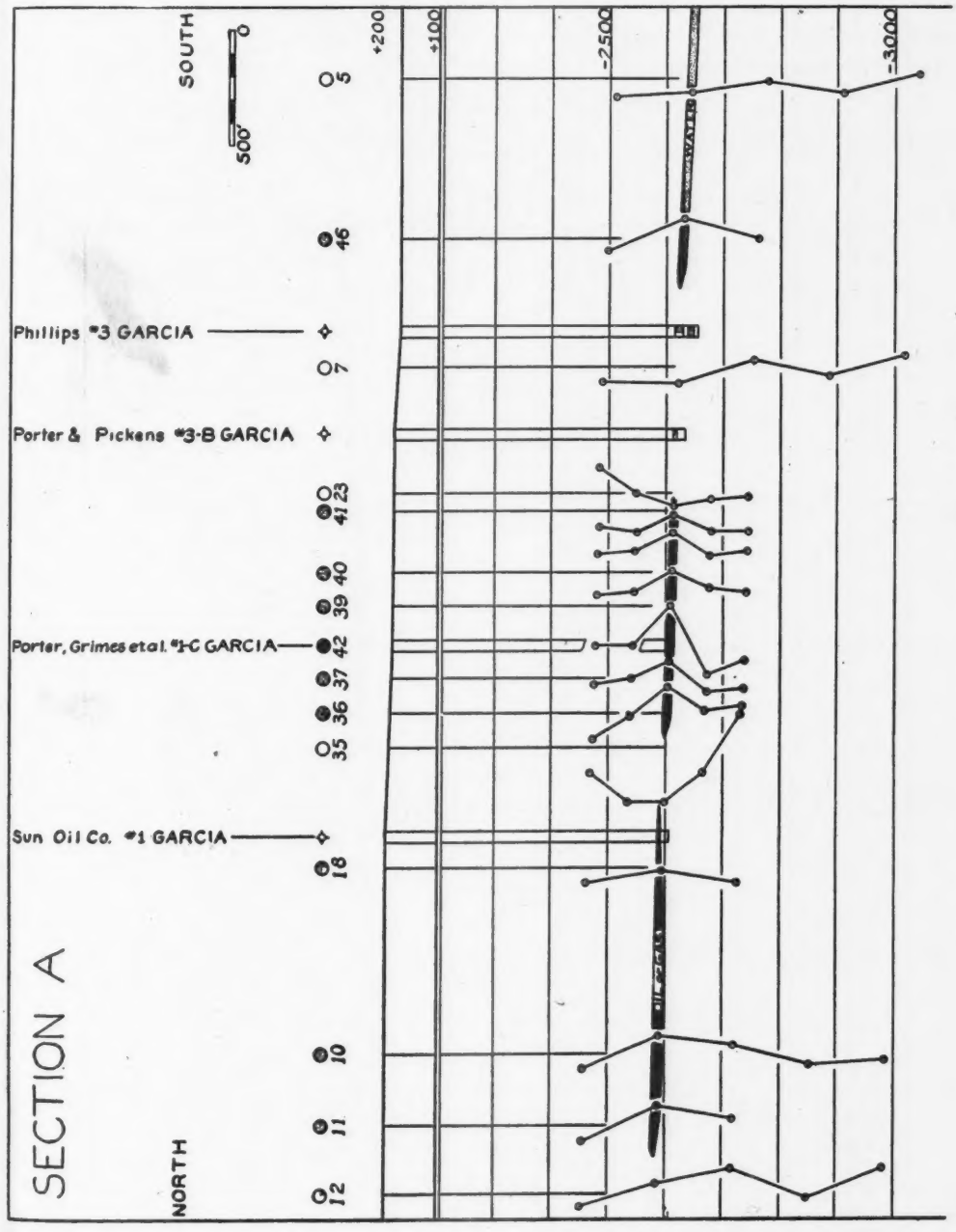


FIG. 15. Subsurface and Resistolog cross-section A of the map of Fig. 14.

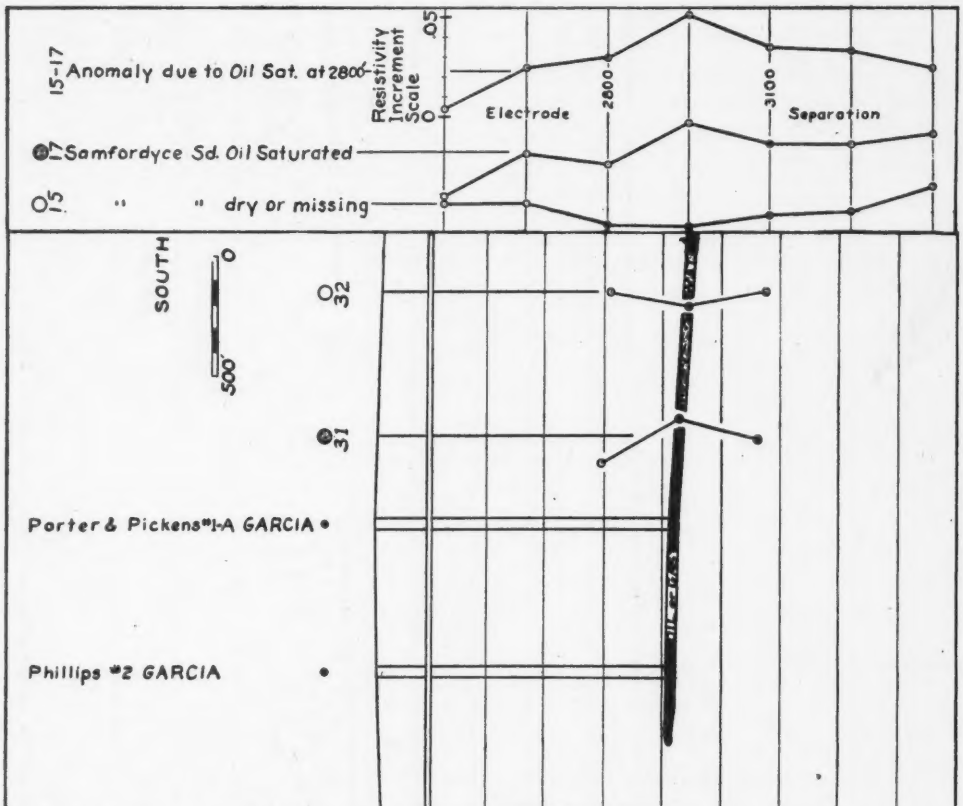
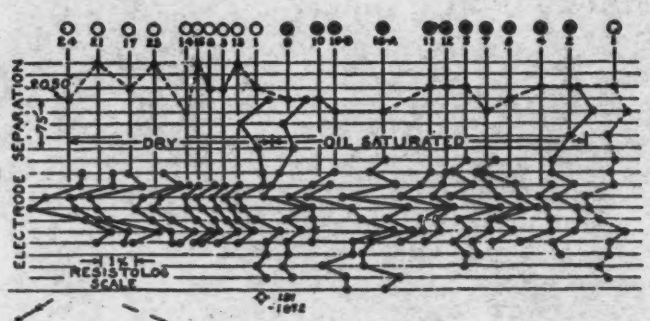


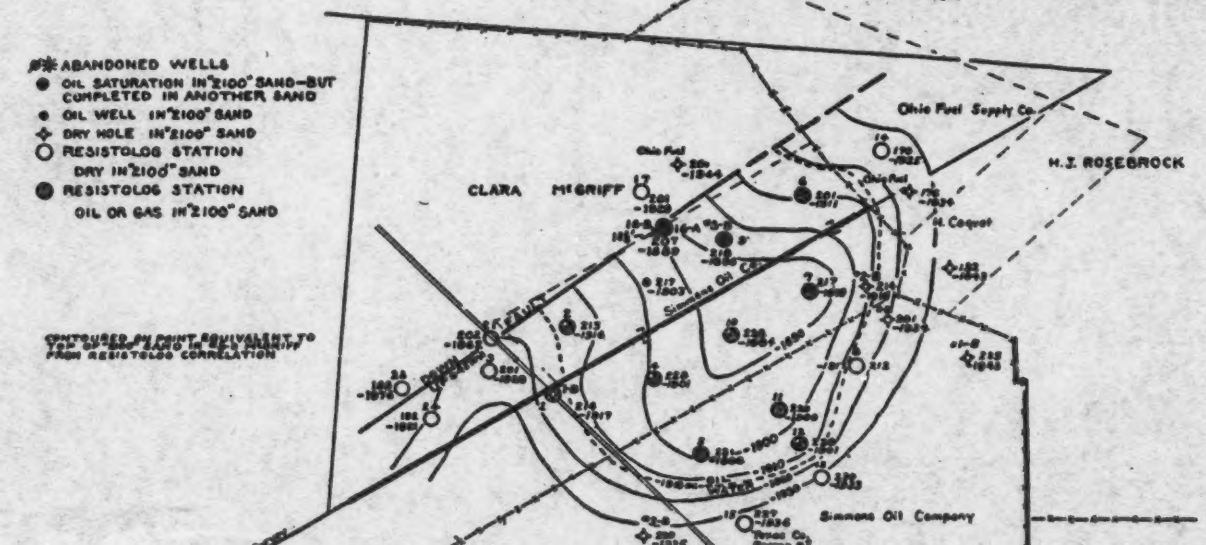
FIG. 16. Subsurface and Resistolog cross-section B of the map of Fig. 14. In the right hand panel are shown Resistologs of stations 15 and 17 of Fig. 14 (on Highway No. 12), which are assumed to be in locations where the SamFordyce sand is dry or missing, or oil saturated, respectively, and their difference.

FIG. 16. Subsurface and Resistolog cross-section B of the map of Fig. 14. In the right hand panel are shown Resistologs of stations 15 and 17 of Fig. 14 (on Highway No. 12), which are assumed to be in locations where the SamFordyce sand is dry or missing, or oil saturated, respectively, and their difference.

RESISTOLOG SURVEY
OF
OAKVILLE FIELD
LIVE OAK CO., TEXAS.

STRUCTURAL & RESISTIVE INTERPRETATION
BASED ON "2100" SAND




ABANDONED WELLS
OIL SATURATION IN "2100" SAND—BUT COMPLETED IN ANOTHER SAND
OIL WELL IN "2100" SAND
DRY HOLE IN "2100" SAND
RESISTOLOG STATION DRY IN "2100" SAND
RESISTOLOG STATION OIL OR GAS IN "2100" SAND
CONTOURED ON POINT EQUIVALENT TO TOP OF "2100" SAND AS DETERMINED FROM RESISTOLOG CORRELATION
CLARA McGRIFF
Ohio Fuel Supply Co.
H. J. ROSEBROCK
H. Coquot
Simmons Oil Company

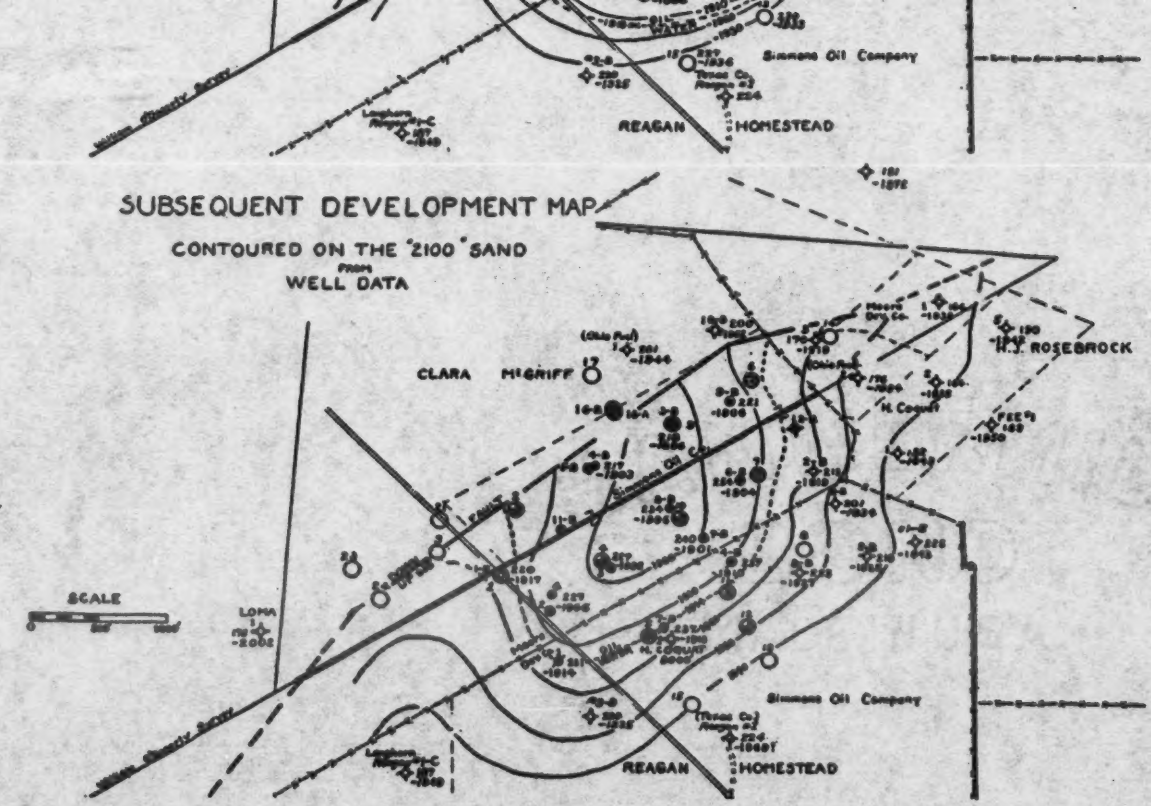


FIG. 17. Results of a Resistolog survey of the "2100 foot" sand of the Oakville field of Live Oak County, Texas. The upper map shows the structural and saturation predictions made from the Resistolog survey at the stage of development shown, and the lower map the subsurface contours and location of the oil-water contact established by the complete development of the field.

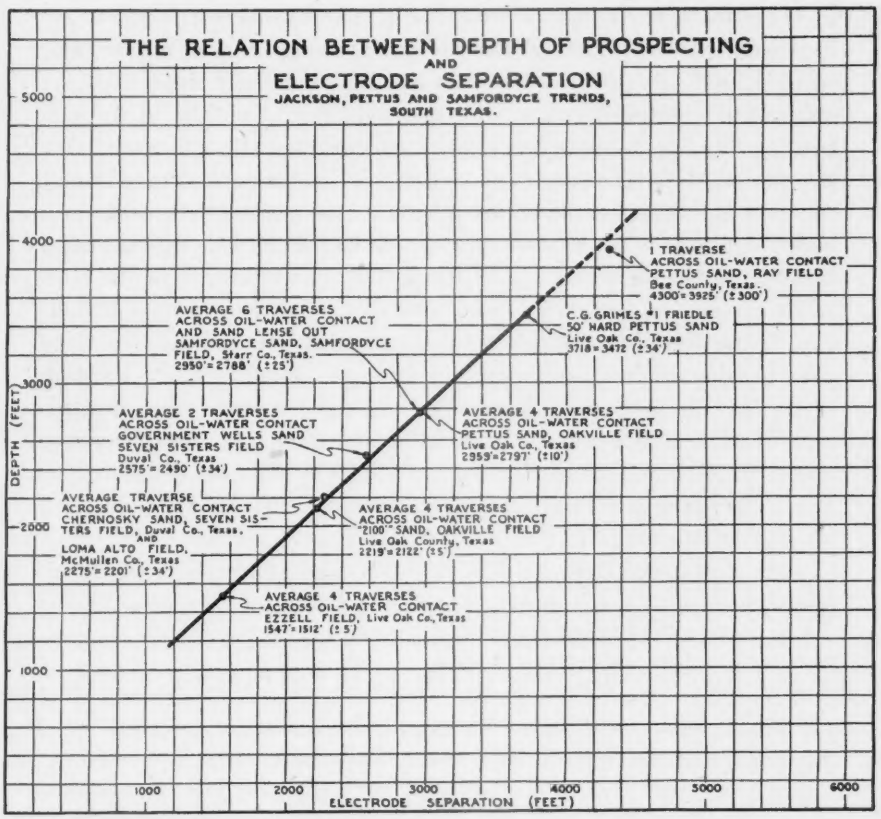

THE RELATION BETWEEN DEPTH OF PROSPECTING AND ELECTRODE SEPARATION
JACKSON, PETTUS AND SAMFORDYCE TRENDS, SOUTH TEXAS.
DEPTH (FEET)
5000
4000
3000
2000
1000
1 TRAVERSE ACROSS OIL-WATER CONTACT PETTUS SAND, RAY FIELD Bee County, Texas. 4300'=3925' (±300')
C.G. GRIMES #1 FRIEDLE 50' HARD PETTUS SAND Live Oak Co., Texas 3718'=3472' (±34')
AVERAGE 6 TRAVERSES ACROSS OIL-WATER CONTACT AND SAND LENSE OUT SAMFORDYCE SAND, SAMFORDYCE FIELD, Starr Co., Texas. 2950'=2788' (±25')
AVERAGE 4 TRAVERSES ACROSS OIL-WATER CONTACT PETTUS SAND, OAKVILLE FIELD Live Oak Co., Texas 2959'=2797' (±10')
AVERAGE 2 TRAVERSES ACROSS OIL-WATER CONTACT GOVERNMENT WELLS SAND SEVEN SISTERS FIELD Duval Co., Texas 2575'=2490' (±34')
AVERAGE TRAVERSE ACROSS OIL-WATER CONTACT CHERNOSKY SAND, SEVEN SISTERS FIELD, Duval Co., Texas, AND LOMA ALTO FIELD, McMullen Co., Texas 2275'=2201' (±34')
AVERAGE 4 TRAVERSES ACROSS OIL-WATER CONTACT "2100" SAND, OAKVILLE FIELD Live Oak County, Texas 2219'=2122' (±5')
AVERAGE 4 TRAVERSES ACROSS OIL-WATER CONTACT EZZELL FIELD, Live Oak Co., Texas 1547'=1512' (±5')
1000
2000
3000
4000
5000
6000
ELECTRODE SEPARATION (FEET)

FIG. 18. Empirical relation between the electrode separation and the depth of prospecting, compiled from traverses across the oil-water contacts and other known subsurface discontinuities along the SamFordyce, Pettus, and Jackson trends of South Texas.

As previously discussed a number of auxiliary tests are applicable to electrical prospecting data of this type by which the origin of any maximum or mimimum observed may be rather conclusively established. One such test is that of similarity of results at nearby stations. Subsurface beds are generally quite uniform laterally. Resistologs at stations 100 and 200 feet apart should therefore ordinarily be practically identical both as to magnitude of features and the electrode separation at which they occur. The duplication throughout an area of Resistologs having numerous features such as those of Figs. 10, 11, 13, 14 and 17 is practically positive proof as to the subsurface origin

of these features. The two most likely sources of error, shallow inhomogeneities and errors of measurement, are random in nature, and would practically never result in Resistologs of definite similarity.

Because of the length of the electrode spread employed in deep prospecting it is necessary to know the location of the subsurface area prospected with reference to the electrode system for accurate lateral location of subsurface boundaries such as the edge of saturation in a given sand or the trace of a fault at a desired level. The experimental location of the subsurface area prospected with reference to the electrode system is based on reversed traverses across a subsurface boundary. If the point in the electrode system which overlies the subsurface area prospected is chosen as the location of the station, the location of the boundary must be determined to be at the same point, regardless of the orientation of the electrode system. Such reversed traverses at stations 15 and 16 of Fig. 14 (on Highway No. 12) disclosed the point overlying the subsurface area prospected to be the point half way between electrodes 1 and 2.

Fig. 10 showed the results of such a reversed traverse in the Branyon field of Caldwell County, Texas, the subsurface boundary being a fault trace in this case.

"2100 Foot Sand" Area of the Oakville Field, Live Oak County, Texas

Fig. 17 shows a detailed structural and direct location survey of the portion of the Oakville field which is productive in the "2100 foot" sand. The position of this sand in the geologic column is indicated on the electric log of Simmons Oil Co. #7 McGriff on the cross section of Fig. 19. The upper 7 feet of the 2100 foot sand is oil saturated in this well as compared with about 17 feet of oil saturation in Simmons Oil Co. #3-B McGriff. The purpose of this survey was the determination of the extent of the oil saturated area in this sand and the associated structural conditions. This survey was also used for determining the value of employing the relation between the edge of the indicated saturated area and structural contours, as determined from Resistolog correlations, as a means of distinguishing oil saturation from other subsurface lateral variations in resistivity.

Resistologs at stations 1 (on the NW-SE road; at McGriff #1-B) and 9 (at McGriff #3-B) were used as standards of comparison for other Resistologs in the area. Simmons Oil Company #1-B McGriff, where station 1 was located, was just below the water level in the 2100 foot sand. Simmons Oil Company #3-B McGriff was the discovery well in this horizon.

All Resistologs covering the 2100 foot sand zone in detail are shown in the correlated position in the upper right-hand corner of Fig. 14. The dotted line designated as 2050′ represents an electrode separation a of this amount. The increment by which potential electrodes were moved was 18.75 feet. Resistologs are plotted so that the feature resulting from an inflection point on the apparent resistivity curve due to a high resistive subsurface layer produces a peak on the Resistolog having an apex which points to the right. Electrode separation increases in the downward direction in this Fig., the electrode separation being 2050 feet or greater for all Resistologs.

All Resistologs obtained in the area are shown as computed. It will be noted that these curves may be divided into two well defined groups, those over the oil saturated area and those off this area. These Resistologs do not appear to have quite so high a degree of similarity as those of Fig. 14. This is due, at least in part, to a difference in the scale of plotting and to the increment by which potential electrodes were moved. The anomaly resulting from oil saturation, as well as general features, are, however, smaller in this case than in case of deeper prospecting. This apparent increase in size of features with depth will be discussed further in connection with Fig. 19.

It will be noted, by reference to Fig. 17, that all stations except station 12 which were interpreted as oil or gas saturated are within the oil saturated area as determined by drill stem tests, this water level being -1914 feet, and that all stations indicated as oil saturated, including 12, are within the oil saturated area as determined by electrical logs, this water level being—1922 feet. As is evident in Fig. 17, the upper map, which was determined from Resistolog data, is quite similar to the subsurface map as determined from well data after complete development, the latter being the lower map of Fig. 17.

The increment of 18.75 feet by which potential electrodes were moved makes possible an error in determination of depth equal to the corresponding variation in depth, or 17 feet, even if the relation between depth of prospecting and electrode separation remains constant. Reference to the subsurface map of Fig. 17 reveals that only the Resistolog at station 7 failed to check actual subsurface data by the amount determined by the increment with which potential electrodes were moved. The error in this case was 29 feet which is 12 feet greater than could be accounted for by lack of detail. This error possibly resulted from refraction of lines of current flow by a hard and high resistive sandstone member which was disclosed to be present in this vicinity by Simmons #6-B McGriff. This sandstone, which occurred

within 50 feet of the surface in this well, was either absent or softer at other locations in the area.

A special test was made to investigate whether the apparent additional detail obtained by moving potential electrodes by an increment of 18.75 feet rather than the usual 37.5 foot or 75 feet increment was not because of a small residual influence of shallow inhomogeneities. For this purpose a second pair of current electrodes *1'* and *2'* were placed 18.75 feet from *1* and *2* respectively, and in the direction of profile. For each position of the potential electrodes separate potential difference measurements were made for current flow between electrodes *1*, *1'*, *2*, and *2'* and the distant electrode *3*. This provided data for calculation of two resistivity increment curves or Resistologs at stations (the point halfway between 1 and 2 and *1'* and *2'*) which were only 18.75 feet apart. Furthermore, a given potential electrode position represented a separation between current and potential electrodes which was 18.75 feet greater for one Resistolog than the other. Any features occurring at a given potential electrode *position* would therefore be apparent upon inspection. This procedure was applied to all stations shown in Fig. 17 having higher number than 16. Stations 16A and 16B were obtained in this way, these stations being only 18.75 feet apart. These Resistologs obviously correlate at the same electrode separation and therefore any influence from shallow inhomogeneities was negligible in comparison to the effect of subsurface features. Similar data were taken at all stations having higher number than 16 but in all other cases these two entirely independent Resistologs have been averaged for the final curve after data of sufficient accuracy was obtained to result in two Resistologs which had similar features. Since these two Resistologs were averaged at the same electrode separation rather than at the same potential electrode positions, any influence of shallow inhomogeneities in the vicinity of potential electrodes will be decreased in magnitude by 50% and distributed between adjacent points. This procedure may be applied more than two times with correspondingly greater distribution and decrease in magnitude of errors. The Resistolog procedure may also be successively applied to such data by taking a ratio between the two resistivity increment values obtained for a given position of the potential electrodes, etc. However, any errors present appear to be principally errors of observation and are more satisfactorily reduced to a negligible quantity by averaging.

It will be noted that the position of the "2100 foot sand" trace of the fault which limits the Oakville field on the Northwest as deter-

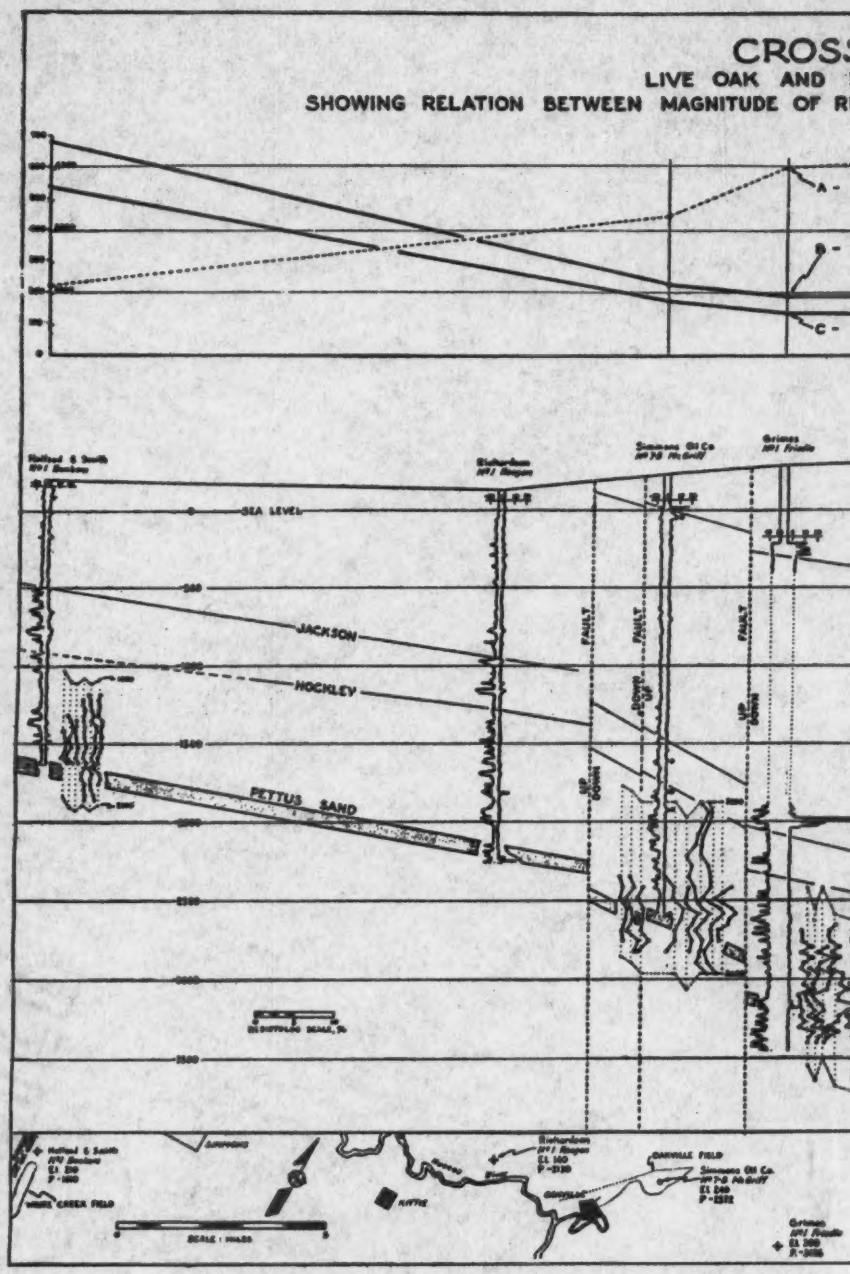
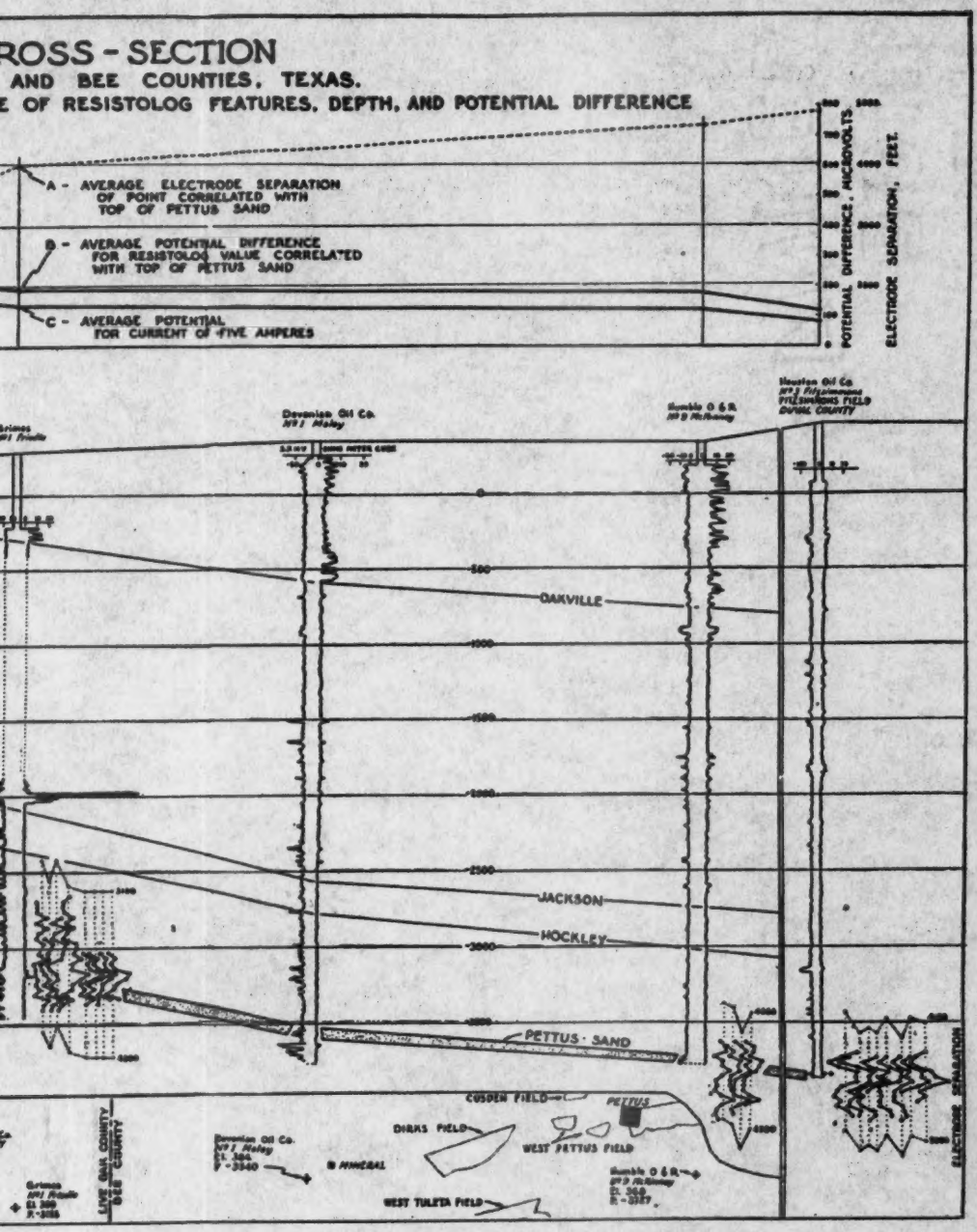


FIG. 19. Regional cross-section 38 miles in length, showing the average electrode sep
difference between potential electrodes separated 600 feet, for the point correlated with th
log anomalies with increase of the depth mapped.


ROSS - SECTION
AND BEE COUNTIES, TEXAS.
E OF RESISTOLOG FEATURES, DEPTH, AND POTENTIAL DIFFERENCE
A - AVERAGE ELECTRODE SEPARATION OF POINT CORRELATED WITH TOP OF PETTUS SAND
B - AVERAGE POTENTIAL DIFFERENCE FOR RESISTOLOG VALUE CORRELATED WITH TOP OF PETTUS SAND
C - AVERAGE POTENTIAL FOR CURRENT OF FIVE AMPERES
POTENTIAL DIFFERENCE, MICROVOLTS
ELECTRODE SEPARATION, FEET
Houston Oil Co. No 1 Fitzsimmons PETTUSBORO FIELD DUVAL COUNTY
Humble O & R. No 9 McKinney
Dawson Oil Co. No 1 Maloy
OAKVILLE
JACKSON
HOCKLEY
PETTUS SAND
CUSDEN FIELD
PETTUS
DIRKS FIELD
WEST PETTUS FIELD
WEST TULETA FIELD
LIVE OAK COUNTY
BEE COUNTY
ELECTRODE SEPARATION

ctrode separation of the point correlated on Electrologs as the top of the Pettus sand; the average potential
d with the Pettus sand; and illustrating an apparent increase in the intensity and correlatability of Resisto-

mined by the Resistolog survey is very close to the position indicated by subsurface data. The indicated displacement of this fault also checks that determined by drilling to within 5 feet, the actual displacement being about 38 feet.

This fault has a displacement of only 16 feet at a depth of 1800 feet and cannot be located by shortening of section or correlation of electric logs at shallower depths. The successful location of a fault having negligible displacement at depths less than 1800 feet provides additional proof as to the depth of prospecting in this area. Neither core drilling to shallow markers nor a seismograph survey gave any evidence of this fault, although its presence was known and a special effort made to find it in both cases.

The various field surveys which have been exhibited and discussed are not in all cases in chronological order, but rather in the order which seemed best fitted to logical exposition of the subject. The order in which the surveys were made is as follows: Fig. 3 (Hart County, Ky.); Fig. 14 (SamFordyce); Fig. 13 (Seven Sisters); Fig. 12 (Pettus); Fig. 10 (Branyon); Fig. 11 (Dunlap); Fig. 17 (Oakville); Fig. 9 (Rhode Ranch).

GENERAL CHARACTERISTICS OF RESISTOLOGS

Fig. 19 is a cross section compiled from electrical well logs which is approximately 38 miles in length extending from the White Creek field of Live Oak County, Texas, to an area immediately down dip from the Pettus field of Bee County, Texas. Resistologs along this traverse are shown in the correlated position and approximately correlated with an electric log in their vicinity.

Resistologs are arranged in order of similarity rather than geographical order along the traverse. A group of Resistologs taken in the Fitzsimmons field of Duval County, Texas and a representative electric log from this field are shown attached to this section. The Fitzsimmons field is about 50 miles Southwest and slightly down dip from the Pettus field, oil production being principally from the Pettus sand.

The area in which each group of Resistologs was taken was in the vicinity of the wells at which the associated electric logs were obtained. Reference lines are shown for each group of Resistologs from which the electrode separation a for any point on each Resistolog may be determined.

Curve A shown above the cross section of Fig. 19 shows the average electrode separation for each group of Resistologs. The electrode

separation given by this curve is the distance from the point halfway between electrodes 1 and 2 to the nearest potential electrode, that is $a+300'$.

The middle curve, B, shows the average potential difference value, for each group of Resistologs, of the point correlated with the Pettus sand. The electrode separation of the potential difference value used in obtaining this average is the distance from electrode *2* to the nearest potential electrode, that is, $a+600'$, this being the smaller of the two potential difference values used in calculating a resistivity increment value.

The lower curve, C, shows the average potential difference value of the point correlated with the Pettus sand for a current flow of 5 amperes. The values of curve C were calculated from those of curve B by dividing the average potential difference value of B by the average current value and multiplying by 5, i.e., $\left(\frac{E\text{ av.}}{I\text{ av.}} \times 5\right)$.

It will be noted from Fig. 19 that if the interval prospected is centered around the Pettus sand, in accordance with the relation between electrode separation and depth shown by Fig. 18, the magnitude of Resistolog features and the similarity of Resistologs in a given area definitely increase with increasing depth to this sand. This phenomenon has been observed consistently in areas along strike from various points of the cross section of Fig. 19. Similar increase in magnitude of features with depth of prospecting have also been noted in other parts of the geologic column. For example, such results were obtained in prospecting centered around the top of the Jackson formation in an area in which this formation occurred at 4800 feet, and in another area in which prospecting was carried approximately 1000 feet below the top of the Pettus sand, the depth of prospecting being approximately 4500 feet.

Where Resistologs have extended from the surface downward they appear to be roughly divisible into three portions. The first of these portions is that extending from the surface to about 1000 feet. In this range very large features obviously associated with shallow beds are obtained. These features exhibit all of the orthodox characteristics of resistivity prospecting predicted by mathematical analysis on the assumption of ohmic conductivity. Resistolog features become increasingly sharp with decrease in depth, very broad features being obtained at the greater depths. Resistivity anomalies of the ohmic type do not appear to terminate in the above range (to 1000 feet) but simply result

in such broad features as to render correlation increasingly difficult. In areas in which high resistive limestones underlie formations having lower resistivity such as the section of Figs. 10 and 11, very broad Resistolog features are obtained with large electrode separation if Resistologs cover sufficient range. For example, the apparent resistivity values in the latter area decrease from the surface down to an electrode separation of roughly 4000 feet after which they gradually begin to increase. The deeper features employed for correlation in this as well as other areas appear to be superimposed on the smooth curves resulting from the above type of variations in subsurface resistivity. Resistologs on the 0–1000 foot range also show marked changes in relation between electrode separation and depth of prospecting which are not obtained in deeper prospecting. Several such shallow traverses on which electric log control was available definitely establish that change in resistivity of the section such as cutting out of high or low resistive members results in a variation in relation between depth of prospecting and electrode separation. Notwithstanding this limitation such surveys may yield information of considerable value, this being particularly true if the problem is the mapping of abrupt changes in depth, or character, of beds such as occurs at the surface trace of a fault. Shallow structural mapping is also possible in areas of sufficiently uniform surface formations, or if well log control is available at several points. Fig. 9 showed an application of the Resistolog procedure to shallow prospecting. Faults, such as that indicated, may be more positively determined by placing stations closer together in the vicinity of the suggested fault. Faults result in an abrupt change in indicated depth from one value to another whereas stratigraphic changes result in a progressive variation of indicated depth, several intermediate values being obtained between the two extremes.

The second of the three portions into which Resistologs may be divided is the range between 1000 feet and about 2000 feet. In this interval Resistolog features are consistently small and are either less consistent than at greater depth or require a higher degree of accuracy of measurement that it was possible to obtain consistently. Several successful surveys have, however, been conducted in this interval but the time required is greater and the results less satisfactory than for deeper prospecting. One case of successful direct detection of oil or gas saturation was obtained in this interval, this being the traverses across the water-oil contact of the Ezzell field of Live Oak and McMullen Counties which are indicated on the curve of Fig. 18. The depth to the

oil sand was only 1500 feet, and the survey was made under known or approximately known subsurface conditions. No cases of definitely successful direct detection of oil or gas saturation at shallower depths have been obtained, although on most such attempts the detail of Resistologs as to increment with which potential electrodes were moved and the accuracy of measurement were not so advantageous as in the Ezzell area. Field results suggest that the difficulty in obtaining satisfactory Resistolog features of the type used for deeper prospecting at depths less than 2000 feet is a result of these features covering an increasingly smaller depth interval with decrease in electrode separation as well as decreasing in magnitude.

The third of the three portions into which Resistologs may be divided is that deeper than 2000 feet. For a given subsurface section Resistolog features appear to increase in magnitude and depth interval covered to at least 6000 feet, the greatest depth to which prospecting has been attempted. As previously stated, Resistolog features are also usually more persistent and definitely correlatable at depths greater than 2000 feet. Of course, it does not follow that large features are always obtained at depths in excess of 2000 feet, the above conclusion being true only for prospecting covering a given geologic column at increasing depths. In some sections such as that shown by the cross sections of Figs. 10 and 11 no large features are obtained on Resistologs to a depth of at least 4000 feet. Since in these cases the beds deeper than 2000 feet are known to be mostly high resistive limes and chalks the suggestion is very strong that the features on which Resistolog correlations are principally based are not contrasts in ohmic resistivity. The resistivity contrast in some of these areas was quite similar, as to the first 2000 feet of section, to that along the Oakville-Pettus portion of the cross section of Fig. 19. In this case the first few hundred feet of section was occupied by high resistive fresh water sands of the Wilcox series resulting in shallow resistivity variation quite similar to that due to fresh water sands in the Oakville series of Fig. 19. The conclusion that Resistolog features are not due to ohmic resistivity is further strengthened by considerable evidence that areas in which the most positive results are obtained both as to structural correlation and direct location of oil are those in which subsurface beds are of relatively low resistivity and show little resistivity contrast. This was true in the Sam Fordyce area as well as in the Seven Sisters, Oakville and Pettus areas for which electric logs are shown.

The reason for the apparent increase in magnitude of Resistolog

features with increase in depth is not established. It is also not determined whether this variation is fundamentally stratigraphic or due to physical changes associated with depth changes. At least two physical changes in the character of geologic sections of the type considered are known to occur with increase in depth—(1) the porosity of the shales decreases and (2) the mineralization of the water with which formations are saturated varies, usually increasing.

Athy has shown[12] that the porosity of shales decreases with increase in depth according to the following formula,

$$f = f_0 e^{-bz}$$

where f is porosity, f_0 is the average porosity of surface clays, b is a constant, and z the depth below the surface. According to Athy the average porosity of surface clays (not fresh deposits) is 45 to 50 percent, while the porosity at 6000 feet is roughly 5 percent.

Carpenter and Spencer[13] have shown experimentally that consolidated sands are substantially incompressible. Results on cores from the Woodbine sand in the East Texas field, as well as on cores from other sands in other areas, indicate a maximum reduction in porosity of 3.6 percent at a pressure of 8000 pounds per square inch. This pressure corresponds to the difference between hydrostatic pressure and pressure due to the weight of overlying formations at a depth of approximately 14,000 feet. The relative incompressibility of sands is also indicated by failure of core analyses of sands to indicate any consistent decrease in porosity with depth which may not be accounted for by change in silt content, grain sorting, cementation, or similar change in character.

On the basis of the above conclusions, the porosity of the shales will progressively decrease while that of associated sands will remain constant as these formations become deeper. Since the magnitude of Resistolog features also increases with depth the accompanying increase in porosity contrast between sands and shales is suggested as a possible explanation for this increase in the magnitude of Resistolog features.

No extensive measurements of porosity of shales are available along the section of Fig. 19. However, several measurements of total porosity of the Pettus sand and the shale immediately above it have

[12] Athy, L. F. *Amer. Assoc. Petrol. Geol. Bull. 14*, 8 (1930).

[13] Carpenter, C. B., and Spencer, G. B. *Oil Weekly*. Dec. 23, 1940.

Carpenter, C. B., and Spencer, G. B. *U. S. Bureau of Mines Report of Investigations 3540*.

been made in the Oakville area. The average depth of shale cores was 2750 feet and the average total porosity 36.4%. The average depth of sand cores was 2773 feet and the average total porosity 37.2%. The method of measuring porosity was by determining the loss in volume when the sample was pulverized to the unconsolidated state. Since the porosities of shales and sands are about equal in the Oakville area it follows from the relation between depth and porosity of shales, that the porosity of shales is probably greater than that of sands of the portion of the section of Fig. 19 which is up-dip from Oakville. Conversely, on the down-dip portion of this section, the shales should have lower porosity than the associated sands. This is based on the assumption that no material change in the porosity of formations occurs other than that resulting from the increase in depth.

Variation in porosity within shale sections also undoubtedly occurs since some shales are probably more compressible than others. Variation in sorting of grains of which the shale is composed would also vary porosity. Relative porosity of sands and shales and variation of porosity within shale sections would not, of course, be reflected by the S. P. or "porosity" diagram of electric well logs, since this curve indicates permeability and difference in electrolytic content of formations relative to that of the drilling mud, rather than porosity.

Available data fail to establish a definite relation between Resistolog features and mineralization of water contained in formations at the level prospected. Since, along the section of Fig. 19, the Pettus sand was at least approximately centrally located in the subsurface interval prospected mineralization of the water produced from this sand should be indicative of the mineralization of formation waters in this interval.

The usual mineral constituents of water from the Pettus sand is indicated by the following analysis of water from Union Producing Co. #18 Ray. This well is located in the Pettus field of Bee County, Texas (Fig. 12). Depth to the Pettus sand was 3927 feet.

Hypothetical Combination	*Parts per Million by wt.*
Silica	2.
Iron and Alumina	2.
Magnesium Carbonate	74.2
Calcium Carbonate	139.2
Sodium Carbonate	217.2
Sodium Sulfate	8.5
Sodium Chloride	13,273.6

As usual for oil field waters sodium chloride is the principal mineral

TABLE I

Depth to Pettus Sand	*Field*	*County*	*NaCl Part sper Million by wt.*
900′	Jacobs	McMullen	8,400
2511′	So. White Creek area	Live Oak	17,100
2750′	Oakville	Live Oak	30,075
3900′	Dirks	Bee	17,480
3930′	Pettus	Bee	13,700
4200′	Fitzsimmons	Duval	26,650
5082′	Southland	Duval	42,000

constituent. Table I, which gives the chloride content, calculated as sodium chloride, of water produced from the Pettus sand in fields on, or along strike from, the section of Fig. 19, should therefore be indicative of mineralization of this water.

It will be noted that the salt content of water from the Pettus sand increases with depth along the section of Fig. 19 to a point in the general vicinity of the Oakville field, and then decreases to the Pettus field. The salt content of water in the Fitzsimmons and Southland fields suggest a general increase in salt content with increase in depth. It is probable that interruption of continuity of beds by faults has resulted in greater variation in mineralization of subsurface waters along this section than would otherwise be the case.

It is possible that greater than normal contrast between the salt content of water in the Pettus sand with respect to that of adjacent shales exists in the Fitzsimmons and Pettus fields. Although the salt content of water from the Pettus sand appears to be relatively low considering the depth, electric log resistivity values suggest that adjacent shales are saturated with water which is not correspondingly low in salt content. Table II gives average electric log resistivity of a uniform shale section, about 100 feet thick, which consistently occurs immediately above the Pettus sand. This shale includes the *Textularia Dibol-*

TABLE II

Area	*No. of Wells*	*Av. Depth To Pettus Sand*	*Av. Mud Res. Ohm-M*	*Av. Res. Diboll Shale*	*Est. Temp. Deg. F*	*Est. Res. Ohm-M at 120° F*
White Creek	5	1897′	3.8	1.20	104	1.06
Oakville	9	2769′	2.3	1.05	115	1.01
Pettus	5	4018′	2.7	1.09	133	1.19
Fitzsimmons	10	4276′	2.5	.89	137	1.02

lensis zone which is employed as a micro-paleontological marker in this area, for which reason it is commonly designated as the Diboll shale. Temperature correction is approximate in Table II because temperature data were not available on all wells. The indicated resistivity values are, however, in close agreement with those of other wells along strike from this section, on which temperature data were available.

Comparison of the electric log resistivity of the Diboll section in the Oakville field with that in the Pettus area is of particular interest. The ratio of the resistivity of water in the Pettus sand in the Pettus field to that of the Pettus sand water in the Oakville field is indicated by salt content to be .49/.24 or 2.04. The ratio of resistivity of the Diboll shale section in the Pettus area relative to that in the Oakville field is 1.19/1.01 or 1.179. This suggests that the salt content of water in the Diboll shale section is greater in the Pettus area relative to the salt content of Pettus sand water than at Oakville. This conclusion is based on the assumption that the porosity of this shale section is at least not greater in the Pettus area than at Oakville.

Consideration that the porosity of shales decreases with depth in accord with Athy's formula[3] suggests that the salt content of the water in the Diboll shale section increases with depth. Tables II and III suggest that resistivity of this shale section remains approximately constant as the depth increases. If the porosity decreases with depth, an increase in mineralization of the water with which the shale is saturated is necessary if the resistivity is to remain constant.

Additional, and more complete, data are being obtained along the above trend as rapidly as made available by drilling operations. The above study of subsurface data in an effort to obtain a theoretical explanation of results established experimentally is preliminary in nature.

All relatively deep prospecting in areas in which large features were obtained involved the measurement of quite small potential difference values, usually between 100 and 200 microvolts. Since approximately the same current flow was employed in all relatively deep prospecting in low resistive areas, the current density at the level prospected was considerably less for large electrode separation. As previously explained, curve B of Fig. 19 shows the average potential difference value for the point correlated with the top of the Pettus sand. It is possible that the smaller current density in the case of deep prospecting had some influence on the magnitude of Resistolog features. However,

several experiments performed in an effort to establish such a relation, although not sufficiently extensive to be conclusive, failed to indicate any variation of the magnitude or character of features with change in magnitude of current. One experiment of this nature in the Oakville area in which current was varied from 0.5 to 7.0 amperes with potential electrodes 600 feet apart and the nearest potential electrode 2800 feet from electrode *1* resulted in a ratio between potential difference and current which varied less than five-tenths of one percent through the range of current variation. A number of Resistologs in the Ezzell area which were taken with current flow of both 3 amperes and 6 amperes failed to show any definite increase in the magnitude of features. Some increase in magnitude was noted with the smaller current flow in one or two cases but the amount of increase was not definitely greater than could be explained by error of observation.

The group of Resistologs shown in Fig. 19 with the electric log of Holland and Smith #1 Bonham are typical of Resistologs in areas along this trend in which depth to the Pettus sand is less than 2000 feet. Although features are quite small in this area it was possible to make fairly reliable structural correlations. The maximum error in determination of depth disclosed by subsequent development in the area was 30 feet.

The group of Resistologs shown with Grimes #1 Friedle represent an apparently positive case in which a high resistive Resistolog feature resulted because of higher than normal resistivity of the Pettus sand due to abnormal cementation and resulting hardness of this formation. Resistologs having the higher electrode separation are on the low side of a down-thrown-to-west fault in this area and near the above well. The existence and location of this fault has been recently verified by core drilling. No attempt was made to study the down dip edge of the high resistive area in relation to structural contours in this case.

The group of Resistologs shown for the Fitzsimmons area were obtained in connection with a survey for mapping the fault which limits oil accumulation on the up-dip or Northwest edge. The Resistologs having the higher electrode separation are those on the low side of this fault, the remainder being near the fault on the high side. The direction and displacement of this fault indicated by Resistolog correlation checked that determined by drilling at all known or subsequently determined points. An apparent shift in the location of the subsurface

area prospected with reference to the electrode system was noted in the vicinity of this fault, the location of this area being shifted towards the potential electrodes by a distance of about 1320 feet or about one fourth the distance between the point half way between electrodes *1* and *2* and the midpoint of potential electrodes. No reversed traverses were made across this fault but the same relation appeared to exist on all traverses in the area. Well casing, pipe lines, and lease boundaries prevented reversed traverses in this case. No attempt was made to determine the relation between depth of prospecting and electrode separation or whether it was possible to detect oil saturation directly in this area because of limitation of time available for this survey. Only one other case has been encountered in which the subsurface area prospected was established as being displaced from the usual position below the point halfway between *1* and *2*, this also being a traverse across a fault.

The group of Resistologs shown in the Oakville and Pettus areas by Fig. 19 have already been discussed.

As suggested by the results at station No. 7 of Fig. 17, variations in the relation between depth and electrode separation have been observed in deeper prospecting although such changes are very much less prevalent than in shallow prospecting. These variations appear to be associated with the cutting out of prominent high resistive members near the surface. This phenomenon has been noted on several traverses across the outcrop of the Oakville sand in which 150 feet to 250 feet of fresh water-saturated sand having resistivity about thirty times that of underlying beds goes out of the section within a mile or less. In all such cases an increase in resistivity of the surface layer resulted in the depth indicated by Resistolog correlations being shallower than the actual. This relation seems to be explained by the bending of current lines away from the normal in passing from the surface layer to subsurface beds of lower resistivity. The intersection of the current lines flowing in subsurface beds, and therefore the apparent current electrode position, would in this case be below the surface, resulting in an apparent decrease in depth. All variations in relation between depth of prospecting and electrode separation observed in deep prospecting appear to have been of this type. As suggested by accompanying data material errors of depth determination are relatively rare in deep prospecting. It should be possible to make correction for errors of this type by means of auxiliary data for determining the thickness and resistivity of the surface layer, or by placing current

electrodes in core drill holes which have been carried through the high resistive surface zone.

ACKNOWLEDGMENT

Acknowledgment is made to Walter McLaren, C. G. Grimes, Grimes, Inc., and F. B. and A. W. Patterson, all of Dayton, Ohio, for extensive aid, both financial and otherwise, in this investigation. Numerous persons and companies who have contributed in various ways, but to lesser extent than the above, are not enumerated because of space requirements.

Acknowledgment is also made to the Henderson Coquat interests of Three Rivers and San Antonio, Texas (i.e., Simmons Oil Company, Longhorn Drilling Company and Moore Development Company), for permission to publish Resistolog and geological data in the Oakville area.

INDEX OF WELLS SHOT FOR VELOCITY*

B. G. SWAN†

ABSTRACT

This index lists 811 wells in which seismic velocity surveys have been made. In so far as possible to obtain, information has been listed concerning the location, survey depth, by whom and when made, and the company or co-operative association responsible for the survey. It is intended that the index be brought up to date at approximately six-month intervals in future issues of GEOPHYSICS.

INTRODUCTION

For many years those engaged in seismograph exploration have been measuring seismic velocities by lowering a geophone in a drill hole and recording shots set off at the surface. In most instances, many companies are quite willing to share the data from a survey with others who are willing to share the expense either at the time the survey is made or at some later date. Such cooperation has been difficult in the past because information regarding the existence and location of old surveys has not been readily available. The chief purpose of this index is to overcome this difficulty. It is to be hoped that it will eventually lead to a wider distribution of velocity information and consequent improvement in the general level of seismic interpretation. It should be emphasized, however, that the listing of a survey in the index does not in any way imply that the data are available for sale or trade.

Without the almost unanimous response of all the seismograph contracting companies, co-operative well velocity survey associations, and oil companies which conduct their own geophysical work, the preparation of this index would not have been possible. This co-operation has been greatly appreciated by the author and the editorial staff of GEOPHYSICS.

Information from which the index is compiled was obtained by direct solicitation from the sources mentioned above. A preliminary index was furnished, and each source was requested to make correc-

* Society members who are particularly concerned with well velocity determinations can secure a reprint of this index by addressing a request to the Business Manager.

† Continental Oil Company, Ponca City, Oklahoma. Serving as Special Editor to assemble this index.

tions and additions from information in their files. From these amended and revised lists, the comprehensive index was assembled.

It is to be expected that some errors in the initial index will be discovered by those who use it to any extent. It is requested that all such errors which withstand careful checking be reported to the editor of GEOPHYSICS and likewise information that is at present lacking on listed wells. Since it is planned to bring the index up to date at approximately six-month intervals, it is also requested that information regarding new surveys made in the future be reported voluntarily by all those having knowledge of the survey. This is important if the index is to be kept current.

The Society plans to prepare enough reprints of the index to provide on request a copy, gratis, to any man in any company who is particularly concerned with well-velocity determinations.

It is intended that the "Depth" heading refer to the maximum depth of the survey. This definition was not made clear when information was first solicited from the various companies, and it is suspected that many may have reported instead the total depth of the well. Corrections reported for errors in this figure will be greatly appreciated.

Little difficulty should be encountered in interpretation of the abbreviations in the "Shot By" column. Under "Sponsored By," however, the meanings of the abbreviations are as follows:

OKWSA = Oklahoma-Kansas Well Shooting Association
CWVSG = Co-operative Well Velocity Survey Group (California)
SSWSA = Southern Seismic Well Survey Association

INDEX OF WELLS SHOT FOR VELOCITY

STATE OF ARKANSAS

County	*Company*	*Lease*	*Location*	*Depth*	*Shot By*	*Date*	*Sponsored By*
Bradley	Placid Oil Co.	No. 2 Murphy	28, 15S-10W	6,300	SEI	1943	Placid
Calhoun	Placid Oil Co.	No. 1 Furlow-Abbott	28, 14S-14W	4,984	SEI	1942	Placid
Chicot	H. L. Hunt	No. 1 Meyers	SE NE 3, 19S-1W	7,118	WGC	1943	Hunt
Columbia	Atlantic	No. 1 Baker	C SW NW 13, T17S-R20W	7,750	NGC	1938	Atlantic
Columbia	Atlantic	No. 1 Pine Woods	Sec. 16, 18S-22W	8,927	NGC	1939	Atlantic
Columbia	Stan. of La.	No. 1 McKean	SW SW 8, 16S-22W	7,200	Stan. La.	1937	
Lafayette	Magnolia	No. 1 Johnston	C NE NW 11, 15S-24W	6,534	Magnolia	1942	Magnolia
Lafayette	Atlantic	No. 9 Bodcaw Lubr.	C NE Sec. 33, T17S-R23E	9,623	NGC	1942	Atlantic
Miller	Barnsdall-TWA	No. 1 Grace	SE NW 4, 15S-27W	6,670	NGC	1943	Barnsdall
Miller	Carter	No. 1 Orr	C SE NW 3, 16S-28W	7,692	Petty	1942	
Miller	Magnolia	No. 9 Olivett	C NE NE 4, 16S-26W	5,790	SEI	1943	Magnolia
Miller	Stan. of La.	No. 1 Harvey	SW SW 33, 16S-26W	5,735	Carter	1937	
Nevada	Benedum Trees	No. 1 Little Block	NE NE SE 7-14S-20W	4,720	SSC	1937	Benedum
St. Francis	Manning & Martin	No. 1 Gregg	SW SW 20, 5N-5E	3,358	IXC	1937	IXC
Union	Hunt	No. 15 Gregory	SW SE 10, 17S-14W	5,790	SSC	1935	SSC

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Butte	Pacific Western	No. 1 Cana	C SW 11, 23N-1W	6,750	WGC	1943	CWVSG
Butte	Superior	No. 1 Dodge Lands	NW NE NE 31, 20N-1E	7,878	Superior	1943	CWVSG
Butte	Richfield	No. 1 Chico	C NE NE 17, 21N-1E		WGC	1943	CWVSG
Colusa	Amerada	No. 1 Calusa Lands	SE SW NE 34, 16N-1W	8,125	GRC	1938	CWVSG
Contra Costa	Shell	No. 1 Heidorn	NW 1/4 4, 1N-2E		UGC	1944	CWVSG
Contra Costa	Standard	No. 1 Prod. Prop.	NW 1/4 23, 3N-3E	6,286	GSI	1941	CWVSG
Fresno	Seaboard	No. 1 Lilllis	NE 1/4 30, 16S-14E	2,875	WGC	1936	CWVSG
Fresno	Western Gulf	No. 1 Skelley Estate	SE 32, 16S-15E	6,450	WGC	1937	CWVSG
Fresno	Tide Water	No. 57-1 Fleishacker	NW SW SE 1, 19S-15E	7,360	GSI	1938	CWVSG
Fresno	Standard	No. 46 13-H	SE NE SW 13, 21S-16E	10,000	GSI	1939	CWVSG
Fresno	K.N.D.A.	No. 54 24-H	SW NE 24, 21S-16E	9,961	WGC	1939	CWVSG
Fresno	Amerada	No. 7-17 S.P.L.	NW SW SW 17, 19S-16E	8,013	GRC	1939	CWVSG
Fresno	Superior	No. 1 P.V.	SE SW 22, 20S-15E	9,000	Superior	1939	CWVSG
Fresno	Shell	No. 48-30 Port Costa	SE SW 30, 17S-16E	10,200	UGC	1939	CWVSG
Fresno	Texas Co.	No. 1 Loescher	SE NE NW 12, 17S-16E	9,593	Texas	1939	CWVSG
Fresno	Superior	No. 1 S.P.L.	NW SW 15, 18S-16E	10,487	Superior	1939	CWVSG
Fresno	Richfield	No. 1 Turk	NW SE NE 4, 17S-15E	8,990	WGC	1939	CWVSG
Fresno	Texas Co.	No. 1 Boston	SE NW NE 14, 20S-18E	10,510	Texas	1940	CWVSG
Fresno	Texas Co.	No. 1 S.P.	NE NE 23, 17S-15E	9,800	Texas	1940	CWVSG
Fresno	Jergins	No. 1 Cheney	NW SW 29, 14S-13E	8,800	GSI	1940	CWVSG
Fresno	Amerada	No. 38-9 S.P.	SW SE SW 9, 19S-16E	8,750	GRC	1940	CWVSG
Fresno	Continental	No. 1 Kreyenhagen	NW NE 4, 22S-16E	11,000	Conoco	1940	CWVSG
Fresno	Texas Co.	No. 27-13 S.P.	NE SW SW 13, 17S-15E	9,650	Texas	1941	CWVSG
Fresno	Shell	No. 8-18 Properties	SW SW 18, 15S-18E	6,400	UGC	1941	CWVSG
Fresno	General Pet.	No. 1 Burrel	NE 1/4 2, 17S-18E	9,370	WGC	1941	CWVSG
Fresno	Richfield	No. 1 Stone-Bragg	SW NW NE 33, 13S-12E	5,700	WGC	1941	CWVSG
Fresno	Amerada	No. 31-34 Clover	NW NE NW 34, 16S-17E	9,400	GRC	1941	CWVSG
Fresno	Amerada	No. 45-26 Lawton	NE SW 26, 17S-19E	8,300	GRC	1941	CWVSG
Fresno	Richfield	No. 1 Ponte	SE NW NW 30, 13S-17E	7,365	WGC	1942	CWVSG

County	*Company*	*Lease*	*Location*	*Depth*	*Shot By*	*Date*	*Sponsored By*
Fresno	General Pet.	No. 45-21 Comm. 8	NE SW 21, 17S-19E	8,257	WGC	1942	CWVSG
Fresno	Amerada	No. 4-6 Truman	SW NW 6, 17S-18E	8,273	WGC	1942	CWVSG
Fresno	Seaboard	No. 53-13 S.T.U.	NW SW NE 13, 15S-17E	6,050	WGC	1942	CWVSG
Fresno	Amerada	No. 58-26 Lawton	SW SE 26, 17S-19E	11,980	GRC	1942	CWVSG
Fresno	Shell	No. 66-22 Henderson	SE NW SE 22, 15S-15E	12,018	UGC	1943	CWVSG
Fresno	Superior	No. 1 White	SW NE 29, 16S-22E	5,450	Superior	1943	CWVSG
Fresno	Superior	No. 54-36 Cantua	SW NE 36, 17S-15E	10,700	Superior	1943	CWVSG
Fresno	Superior	No. 81-22 Kreyenhagen	NE NE 22, 17S-18E	9,500	Superior	1943	CWVSG
Fresno	Shell	No. 1-1 San Joaquin	C NE SW 10, 15S-17E		UGC	1943	CWVSG
Fresno	Shell	No. 73-35 S.P.	NW SE NE 35, 15S-15E		UGC	1944	CWVSG
Glenn	Superior	No. 2 Dodge Lands	SW SW 7, 19N-1E	5,350	Superior	1943	CWVSG
Glenn	Superior	No. 1 Knight	NE SW SE 13, 21N-2W		Superior	1943	CWVSG
Glenn	Superior	No. 72-20 Glenn	SW NE SE 31, 21N-1W		Superior	1943	CWVSG
Kern	Standard	No. 10-1 K.C.L.	SW SE NW 20, 30S-26E	8,100	GSI	1936	CWVSG
Kern	Standard	No. 11-1 K.C.L.	NE NE 19, 29S-26E	7,600	GSI	1936	CWVSG
Kern	Ohio	No. 2 T.I.T.	NE NW SE 21, 11N-19W	6,500	UGC	1937	CWVSG
Kern	Superior	No. 1 Crome Comm.	in SW NW 36, 29S-28E	5,000	Superior	1937	CWVSG
Kern	Superior	No. 8 K.C.L.	NE NW 11, 30S-26E	10,500	Superior	1937	CWVSG
Kern	Union	No. 85-34 K.C.L.	NE SE 34, 28S-25E	11,240	WGC	1937	CWVSG
Kern	Texas Co.	No. 1 Martin	SW SW 22, 27S-20E	7,800	Texas	1937	CWVSG
Kern	Superior	No. 1 Krause	NW NW 21, 29S-26E	8,132	Superior	1938	CWVSG
Kern	Continental	No. B-1 K.C.L.	NW SW NW 12, 29S-26E	9,350	Conoco	1938	CWVSG
Kern	Texas Co.	No. 1 Bastion	NW SW NE 34, 30S-29E	4,620	Texas	1938	CWVSG
Kern	Continental	No. A-2 K.C.L.	SW NW SW 8, 27S-24E	13,000	Conoco	1938	CWVSG
Kern	Shell	No. 76-16 K.C.L. 1-B	SW NE SE 16, 29S-26E	7,467	UGC	1938	CWVSG
Kern	Standard	No. 11-2 K.C.L.	SW NW NW 20, 29S-26E	11,300	UGC	1938	CWVSG
Kern	Ohio	No. 8 K.C.L.-A	SW SW SE 32, 31S-26E	11,170	WGC	1938	CWVSG
Kern	Shell	No. 83-35 K.C.L.-A	NE SE NE 35, 26S-25E	10,000	UGC	1938	CWVSG
Kern	Tide Water	No. 1-17 K.C.L.	NW NE SE 17, 26S-25E	9,100	WGC	1938	CWVSG
Kern	Shell	No. 4-26 K.C.L. 1-A	SW NW 26, 11N-22W	9,450	UGC	1938	CWVSG
Kern	Superior	No. 1 Helbling	NE NW 1, 29S-25E	13,925	Superior	1938	CWVSG
Kern	Texas Co.	No. 1 C.W.L.	NE SE 7, 29S-27E	9,500	Texas	1938	CWVSG
Kern	Continental	No. 1 K.C.L.-E	SE SW NW 17, 30S-26E	8,170	Conoco	1938	CWVSG
Kern	Shell	No. 47-14 K.C.L.-A	NE SE SW 14, 30S-25E	8,175	UGC	1938	CWVSG
Kern	Texas Co.	No. 1 C.W.L.	NE SE 7, 29S-27E	10,140	Texas	1938	CWVSG
Kern	Shell	No. 58-8 K.C.L.-A	SW SE 8, 27S-26E	9,250	UGC	1938	CWVSG
Kern	Superior	No. 12 K.C.L.	SE NE NE 3, 30S-26E	11,100	Superior	1939	CWVSG
Kern	Superior	No. 1 Clerico	in NE SW 26, 29S-28E	3,300	Superior	1939	CWVSG
Kern	Calif. Lands	No. 2 Occidental	NE SW 24, 26S-20E	4,825	UGC	1939	CWVSG
Kern	Richfield	No. 1 Union Ave.	SE NE SW 6, 30S-28E	10,000	WGC	1939	CWVSG
Kern	Richfield	No. 52-32 K.C.L.-A	SW NW NE 32, 30S-25E	8,200	WGC	1939	CWVSG
Kern	Amerada	No. 6 Beer	NE NW 21, 26S-19E	4,569	GRC	1939	CWVSG
Kern	Ohio	No. 2 K.C.L.-F	SW NE NE 10, 31S-25E	9,200	GGC	1939	CWVSG
Kern	Texas Co.	No. 35-1 K.C.L.	in NW NE 35, 28S-26E	8,810	Texas	1939	CWVSG
Kern	Shell	No. 23-2 K.C.L.-2A	NE SW NW 2, 29S-26E	9,500	UGC	1939	CWVSG
Kern	Shell	No. 87-4 K.C.L.-B	NE SE SE 4, 30S-25E	13,750	UGC	1939	CWVSG
Kern	Standard	No. 2 K.C.L.-8B	C N/2 NW NW 17, 27S-24E	13,000	UGC	1939	CWVSG
Kern	Union	No. 1-36 Kernco	C W/2 SW 36, 27S-24E	12,000	WGC	1939	CWVSG
Kern	Calif. Lands	No. 1 C.D.S.	NE NE 7, 29S-24E	11,050	WGC	1939	CWVSG
Kern	Richfield	No. 3 Belridge	NW SE SW 22, 27S-20E	8,000	WGC	1939	CWVSG
Kern	Western Gulf	No. 1 Panhandle	SW NE 3, 32S-26E	9,900	GGC	1939	CWVSG

County	Company	Lease	Location	Depth	Shot By	Date	Sponsored By
Kern	Meridian	No. 2 Fee	in SW NE NW 23, 29S-27E	7,910	GGC	1939	CWVSG
Kern	General Pet.	No. 1 Sullivan	SE NE 12, 29S-25E	11,233	WGC	1939	CWVSG
Kern	Continental	No. D-2 K.C.L.	SE NW SW 14, 30S-26E	13,850	Conoco	1939	CWVSG
Kern	Union	No. 4-23 Bowerbank	SW NW 23, 29S-24E	11,565	WGC	1940	CWVSG
Kern	Richfield	No. 81-36 B.V.A.	NE NE 36, 31S-25E	10,000	WGC	1940	CWVSG
Kern	Richfield	No. 1 James Slough	SW NW SW 6, 31S-26E	10,232	WGC	1940	CWVSG
Kern	Tide Water	No. 65-13 K.C.L.-B	NE NW SE 13, 31S-25E	11,000	WGC	1940	CWVSG
Kern	Shell	No. 52-13 K.C.L.-2A	SW NW NE 13, 11N-22W	12,300	UGC	1940	CWVSG
Kern	General Pet.	No. 1 B.V.A.	in SW NW 1, 32S-24E	11,800	WGC	1940	CWVSG
Kern	Continental	No. 1 Meyer	NE SW 7, 27S-24E	12,890	Conoco	1940	CWVSG
Kern	Continental	No. 1 Community	NE NE 12, 28S-24E	12,980	Conoco	1940	CWVSG.
Kern	Western Gulf	No. 45 K.C.L.-B	SE NE SW 22, 29S-27E	10,500	UGC	1940	CWVSG
Kern	Shell	No. 45-9 B.V.A.	NE SW 9, 32S-25E	11,413	UGC	1940	CWVSG
Kern	Union	No. 1 Fitz-Western	SE NE 13, 29S-21E	7,466	WGC	1940	CWVSG
Kern	Oil Scout	No. 1 Tejon	SW NW 27, 32S-29E	6,950	Texas	1940	CWVSG
Kern	General Pet.	No. 1 K.P.C.	NE NW SW 16, 26S-22E	6,000	WGC	1940	CWVSG
Kern	Superior	No. 3-1 Osborne	NE NW SE 28, 28S-25E	11,338	Superior	1940	CWVSG
Kern	Superior	No. 1 Brandt	SE SE 28, 29S-26E	11,500	Superior	1940	CWVSG
Kern	Texas Co.	No. 1 McDonald-Theta	C N/2 NE SW 12, 28S-19E	5,100	Texas	1940	CWVSG
Kern	Union	No. 41-34 Kernco	NE NW 34, 28S-25E	11,470	WGC	1939	CWVSG
Kern	Union	No. 25-34 Kernco	NE NW SW 34, 28S-25E	11,425	WGC	1940	CWSVG
Kern	Western Gulf	No. 12-12 K.C.L.-B	SW NW NW 12, 32S-26E	10,100	Texas	1941	CWSVG
Kern	Union	No. 52-28 Crites	C W/2 SW SW 28, 28S-25E	11,262	WGC	1941	CWSVG
Kern	Superior	No. 13 K.C.L.	NE SE SE 18, 29S-25E	10,110	Superior	1941	CWSVG
Kern	C.C.M.O. Co.	No. 12-1 Famosa	NW SE NW 12, 27S-26E	6,430	WGC	1941	CWSVG
Kern	Union	No. 31-3 Kernco	NW NE NW 3, 30S-26E	12,370	WGC	1941	CWSVG
Kern	Texas Co.	No. 47-15 S.P.	NE SE SW 15, 29S-24E	11,950	Texas	1941	CWSVG
Kern	Tide Water	No. 46-8 Quinn	SE NE SW 8, 25S-27E	3,771	WGC	1941	CWSVG
Kern	Union	No. 81 Morgan	NE NE 14, 32S-26E	11,425	WGC	1941	CWSVG
Kern	Shell	No. 52-21 Bell	SW NW NE 21, 25S-26E	6,265	UGC	1941	CWSVG
Kern	Richfield	No. 1 Kramer	SE NW NW 34, 28S-27E	7,712	WGC	1941	CWSVG
Kern	Western Gulf	No. 12-7 Symons	SW NW NW 7, 32S-27E	11,000	UGC	1941	CWSVG
Kern	General Pet.	No. 51-15 S.P.L.	NW NE 15, 28S-24E	13,910	WGC	1942	CWSVG
Kern	Standard	No. 22-43 K.C.L.	NE SE NW 31, 30S-25E	8,800	GSI	1942	CWSVG
Kern	Western Gulf	No. 58-21 Jack	SW SW SE 21, 28S-25E	11,575	WGC	1942	CWSVG
Kern	Shell	No. 1 Curry	C NE SW 20, 25S-26E	7,200	UGC	1942	CWSVG
Kern	Belridge Oil	No. 47-27 Sec. 27	C S/2 NE SE 27, 27S-20E	8,285	WGC	1942	CWSVG
Kern	Shell	No. 23-6 Williams	NE SW NW 6, 28S-20E	2,650	UGC	1942	CWSVG
Kern	Shell	No. 84-27 K.C.L.-B	SE SE NE 27, 30S-26E	8,352	UGC	1943	CWSVG
Kern	Standard	No. 12-6 K.C.L.	SW NE 30, 29S-26E		GSI	1943	CWSVG
Kern	Richfield	No. 1 K.C.L.	NE SW 3, 31S-26E		GSI	1944	CWSVG
Kern	Western Gulf	No. 37-14 K.C.L.-A	NW SE SW 14, 29S-26E		GSI	1944	CWSVG
Kern	Superior	No. 10 K.C.L.	3, 30S-26E	7,790	Superior	1937	CWSVG
Kern	Ohio	No. D-1 T.I.T.	21, 11N-19W	6,500	?	?	?
Kings	Shell	No. 6-4 Cohn Estate	SW NW SW 4, 22S-19E	11,800	UGC	1940	CWSVG
Kings	Standard	No. 1-1-U Fee	NW NW 1, 23S-18E	10,810	GGC	1940	CWSVG
Kings	Von Glahn	No. 1 Von Glahn	SW NW 4, 23S-22E	9,700	UGC	1942	CWSVG
Kings	Continental	No. 1 Drummond	SW SW 36, 18S-22E	7,850	UGC	1942	CWSVG
Kings	Shell	No. 21-28 T.S.G.	SE NW NW 28, 22S-20E	12,350	UGC	1943	CWSVG
Los Angeles	General Pet.	No. 177F Santa Fe	SE NE 6, 3S-11W	6,9[illegible]	GSI	1936	CWSVG

County	*Company*	*Lease*	*Location*	*Depth*	*Shot By*	*Date*	*Sponsored By*
Los Angeles	Texas Co.	No. 17 Baldwin	6, 2S-11W	6,300	Texas	1937	CWSVG
Los Angeles	Texas Co.	No. 5 Security	NW SW NW 18, 3S-14W	7,300	Texas	1937	CWSVG
Los Angeles	Texas Co.	No. 5-1 Gardena	Center of Sec. 30, 3S-13W	6,000	Texas	1938	CWSVG
Los Angeles	Wilshire	No. 1 Construction	12, 3S-15W	7,380	UGC	1938	?
Los Angeles	Texas Co.	No. 1 Anderson-Spring	SW SE 9, 2S-15W	7,107	Texas	1939	CWSVG
Los Angeles	El Rev Oil Co.	No. 1 Westmore	C W/2 SE SE 2, 3S-14W	8,596	UGC	1940	CWSVG
Los Angeles	Union	No. 79 Callender	32, 3S-13W	12,487	UGC	1941	CWSVG
Los Angeles	Wilshire	No. 1 Community	SE NE 14, 3S-11W	8,948	UGC	1941	CWSVG
Los Angeles	Texas Co.	No. A-3 McMally	C N/2 N/2 NW 22, 3S-11W	9,500	WGC	1943	CWSVG
Madera	Seaboard	No. 1 Gill	SE NW SW 27, 12S-15E	6,400	WGC	1937	CWSVG
Madera	Shell	No. 74-9 Chowchilla	SW SE NE 9, 11S-14E	9,000	UGC	1941	CWSVG
Madera	Texas Co.	No. 38-16 Gill	SW SE SW 16, 13S-16E	9,040	UGC	1943	CWSVG
Madera	Shell	No. 38-18 Gill	* 18, 13S-16E	5,966	UGC	1943	CWSVG
Merced	Amerada	No. 1 Carano	C S/2 NW SW 19, 10S-11E	5,000	GRC	1938	CWSVG
Merced	Seaboard	No. 1 Howard	C N/2 NE SW 6, 8S-11E	6,900	WGC	1939	CWSVG
Merced	Tide Water	No. 37-18 Turlock	NW SE SW 18, 6S-11E	6,450	WGC	1942	CWSVG
Merced	Shell	No. 75-11 Alberti	NW NE SE 11, 10S-11E		UGC	1943	CWSVG
Orange	Continental	No. 1 Santa Ana	SW SE NW 14, 5S-10W	4,400	Conoco	1935	CWSVG
Orange	Texas Co.	No. A-13-1 Anaheim	C E/2 NW 8, 4S-10W	8,825	Texas	1939	CWSVG
Orange	Texas Co.	No. 1 Spencer	SE NE NE 1, 4S-11W	9,450	UGC	1942	CWSVG
Orange	Standard	No. 129 Murphy	C N/2 SE SW 18, 3S-10W	9,000	UGC	1942	CWSVG
Sacramento	Feldman, D. D.	No. 1 Unit Plan	SE SW 8, 7N-6E	4,500	UGC	1943	CWSVG
Sacramento	Richfield	No. 1 Natomas	NE SW NW 17, 10N-4E	4,960	WGC	1943	CWSVG
San Joaquin	Amerada	No. 1 F.D.L.	SE SE 15, 2S-5E	5,675	GRC	1935	CWSVG
San Joaquin	Texas Co.	No. 1 L. Stephen	NE NW NE 8, 1S-6E	5,400	Texas	1937	CWSVG
San Joaquin	Standard	No. 2-1 Woods Comm.	SW SE NW 23, 1N-5E	5,000	GSI	1942	CWSVG
San Joaquin	Amerada	No. 9-1 Lodi Comm.	NW SE 9, 4N-7E	4,442	GRC	1943	CWSVG
San Joaquin	Bankline Oil	No. 1-1 Community	NW SW SE 1, 4N-6E	5,600	GSI	1943	CWSVG
San Joaquin	Amerada	No. 1 Housken	C W/2 NE SE 28, 5N-5E	5,592	GRC	1943	CWSVG
San Joaquin	Standard	No. 1 Roberts Is.	NE NW SE 36, 1N-5E		GSI	1943	CWSVG
San Joaquin	Standard	No. 3 Blewett	SW SW 23, 3S-6E		GSI	1943	CWSVG
San Joaquin	Standard	No. 1 Mandeville	5, 2N-4E		GSI	1944	CWSVG
San Joaquin	Standard	No. 1 Gerhart	in NW SW 24, 2S-5E		GSI	1944	CWSVG
San Joaquin	Standard	No. 1 Fairoaks	19, 1N-7E		GSI	1944	CWSVG
Santa Barbara	Fred Cole	No. 1 Gicomini	28, 10N-35W	4,663	WGC	1940	CWSVG
Santa Barbara	Texas Co.	No. A-1 Bishop	13, 4N-29W	4,340	Texas	1940	CWSVG
Solano	Amerada	No. 1 Happe	C NE 22, 4N-2E	6,500	GRC	1936	CWSVG
Solano	Standard	No. 1 Calif. Pack.	in NW 15, 5N-2E	6,734	GSI	1939	CWSVG
Solano	Amerada	No. 1 Starkey	C SE 2, 6N-2E		GRC	1943	CWSVG
Stanislaus	Don Pedro Oil	No. 1 Don Pedro	NE NE 9, 6S-9E	4,060	UGC	1942	CWSVG
Stanislaus	Texas Co.	No. 1 Bacon	30, 6S-8E	1,100	Texas?	?	CWSVG
Sutter	Shell	No. 1 Buttes	C N/2 N/2 SE 2, 15N-1E	6,091	UGC	1943	CWSVG
Sutter	Shell	No. C-1 Buttes Comm.	SE NE 12, 16N-1E		UGC	1943	CWSVG
Tulare	Seaboard	No. 1 Security	NW SE 16, 23S-26E	4,075	WGC	1937	CWSVG
Tulare	Tide Water	No. 35 Danials	NW NE SW 22, 24S-23E	11,650	WGC	1940	CWSVG
Tulare	Texas Co.	No. 77-1 G. & L.	NW SE SE 1, 24S-26E	3,475	Texas	1941	CWSVG
Tulare	Richfield	No. 1 Hewitt	NW SW 1, 21S-25E	3,475	WGC	1941	CWSVG
Tulare	Continental	No. 1 Pixley Comm.	NW SW 9, 23S-25E	7,880	Conoco	1942	CWSVG
Tulare	Richfield	No. 1-1 No. Tulare	SW SW 33, 19S-24E	5,343	WGC	1942	CWSVG
Tulare	W. H. Fortine	No. 1 Mosesian	22, 22S-26E	3,000	UGC	1936	CWSVG

County	*Company*	*Lease*	*Location*	*Depth*	*Shot By*	*Date*	*Sponsored By*
Ventura	Texas Co.	No. 1 Montgomery	13, 2N-22W	7,000	Texas	1941	CWSVG
Ventura	Royalty Serv. Corp.	No. 1 Leonard	29, 2N-22W	8,397	GSI	1942	CWSVG
Yolo	Amerada	No. 1 F. & C.	4, 6N-3E	7,200	UGC	1941	CWSVG
Yolo	Shell	No. 1 Glide	C SW 15, 7N-3E	5,800	UGC	1943	CWSVG
Yolo	Superior	No. 1 Oesta	SE NE 10, 8N-1E		Superior	1944	CWSVG
			STATE OF COLORADO				
Kiowa	Gulf	No. 1 Risser	C SW NE 1, 17S-50W	6,145	SSC	1937	OKWSA
Lincoln	Gulf	No. 1 Smith	C SW SE 19, 15S-53W	6,100	Gulf	1937	OKWSA
Moffat	Stan.-Cont.	No. 1 Hanawalt	NE SE SE 4, 6N-92W		Texaco	1944	
Prowers	Trojan	No. 1 Lotus	NE NE 15, 23S-46W	5,332	CGC	1935	OKWSA
			STATE OF GEORGIA				
Mitchell	Stanolind	No. 1 J. H. Pullen	Lot 133, Land Dist. No. 10		Shell	1944	
			STATE OF ILLINOIS				
Edwards	Leach Bro's.	No. 1 Ellen	3, 2S-10E				
Effingham	Kingwood Oil	No. 1 McWhorter	SE NW 15-6N-6E	6,528	SSC	1939	Kingwood
Marion	Carter	No. 1 Metzger	C W 1/2 NW SE 4, 4N-3E	3,675	SSC	1937	OKWSA
Montgomery	Gulf	No. 1 Brandon	NW SE SE 1, 10N-5W		Gulf		Gulf
Moultrie	Seaboard	No. 1 Doy Horn	29, 13N-5E	3,165	IXC	1939	IXC
Richland	Ohio Oil	No. 1 Arbuthnot	NW NW 8, 3N-9E	2,973	GGC	1937	Ohio?
White	Kingwood Oil	No. 1 Martin	SW NE 13, 7S-8E	5,220	SSC	1940	Kingwood
			STATE OF INDIANA				
Posey	Carter Oil	No. 1 Graulich	NW NW 4, 7S-14W	4,938	IXC	1938	IXC
			STATE OF KANSAS				
Barber	Pure	No. 1 Palmer	SE NE SW 10, 33S-10W	4,700	SSC	1937	OKWSA
Barton	Sinclair-Pr.	No. 1A Davidson	9, 16S-11W	3,343	Petty	1937	OKWSA
Barton	Derby Oil	No. 1 Berscheidt	12, 20S-11W	3,000	GRC	1932	
Barton	C. C. Millerd Sy	No. 1 Boertz	13, 18S-12W	3,400	GRC	1931	
Brown	Carter	No. 1 Strat. Test	SW SW SW 24, 4S-16E	3,475	Carter	1939	
Clark	Olson Oil	No. A1 Morrison	C SE SW 17, 32S-21W	6,458	GSI	1941	
Cowley	Barrett et al	No. 8 Waite	SW NW 21, 31S-4E	3,100	Shell	1939	OKWSA
Decatur	Helmerich-Payne	No. 1 Penn	NW NW SW 16, 2S-29W		SSC	1943	Texas
Decatur	Stanolind	No. 1 Hale	SE SE SE 32, 23S-26W	4,019	Stanolind	1943	
Edwards	Stanolind	No. 1 Arensman	NE SE 23, 25S-19W	5,065	Stanolind	1941	OKWSA
Edwards	Amerada	No. 1 Tansil	32, 25S-19W	4,950	GRC	1929	
Ellis	Stanolind	No. 1 Furthmeyer	SE SE SE 25, 12S-16W	3,025	GSI	1932	OKWSA?
Ellis	Gypsy	No. 2 Kozisek	NE SE SE 16, 16S-10W	3,300	SSC	1934	Carter
Ellis	Darby	No. 1 Younger	NW NW NW 20, 13S-17W	3,605	SSC	1941	Sunray?
Ellsworth	Elwell et al	No. 1 Springer	NE NW NW 35, 18S-10W	3,278	SSC	1934	
Ellsworth	Gypsy	No. 2 Kozisek	NE SE SE 16, 16S-10W	3,300	SSC	1934	OKWSA
Gray	Champlin	No. 1 Becker	C NE SW 34, 28S-29W	6,270	Stanolind	1939	OKWSA
Hamilton	Barnsdall-Denv.	No. 1 Porter	SW NE 30, 25S-41W	3,000	Shell	1937	OKWSA
Harper	Amerada	Mandeville	24, 34S-6W	4,761	GRC	1929	GRC

County	*Company*	*Lease*	*Location*	*Depth*	*Sho tBy*	*Date*	*Sponsored By*
Harper	Barry	No. 1 Anthony	17, 31S-9W	4,812	GRC	1934	GRC
Harper	Amerada-Dixie	No. 1 Misak	25, 34S-6W	5,100	GRC	1931	
Harvey	Shell	No. 1 Neufeldt	SE SW NW 8, 22S-3W	3,406	SSC	1934	OKWSA
Kearney	Stanolind	No. 1 Judd	SE SE 15, 21S-38W	5,275	Stanolind	1940	Stanolind
Kingman	Skelly	No. 1 Rouse	C N/2 SE 20, 27S-10W	4,282	Empire	1934	OKWSA
Logan	Texas	No. 1 Smith	NE NE SW 30, 11S-36W	5,321	Texaco	1943	OKWSA
McPherson	Darby	No. 5 Coons	NW NE SW 20, 19S-1W	3,361	SSC	1934	Carter
Mitchell	Carter	No. 1 Victor (Strat. Test)	SE SW 20, 9S-7W	3,725	Carter	1939	
Osborne	Carter	No. 1 Neushwanger	SW NE SW 15, 8S-14W	3,774	Carter	1943	Carter
Osborne	N. Ordnance	No. 1 Vandement	C NW NW 3, 9S-13W	4,118	Carter	1943	Carter
Ottawa	Stanolind	No. 1 Duggan	NW NW SW 12, 12S-1W	3,360	Stanolind	1943	
Pawnee	Adair & Morton	No. 1 Thompson	NW NE NW 16, 22S-20W	4,960	SSC	1942	OKWSA
Phillips	Carter	No. 1 Robb	SE SW 3, 4S-18W	3,574	Carter	1942	Carter
Pratt	Skelly	No. 1 Gilcreast	CSE 7, 28S-11W	4,200	SSC	1935	OKWSA
Pratt	Lario	No. 1 Lemon	SE SE NW 12, 29S-13W	4,360	GRC	1936	OKWSA
Reno	Roth & Faurot	No. 1A Yoder	C NW NW 15, 24S-5W	3,915	SSC	1934	OKWSA
Reno	Stanolind	No. 1 Hilger	SE SE NW 16, 26S-4W	3,944	GRC	1936	OKWSA
Reno	Sinclair-Pr.	No. 1 Shephard	SE SE NW 22, 26S-9W	4,333	SSC	1934	OKWSA
Reno	Tatlock Oil	No. 1 Vernon Tonn	17, 25S-4W	4,000	GRC	1932	
Rice	Dietrick et al	No. 1 Fitzpatrick	C NE NE 30, 21S-8W	3,628	SSC	1934	OKWSA
Rice	Continental	No. 1A Lansing	NE NE SW 25, 18S-8W	3,100	GRC	1934	OKWSA
Rice	Elwell et al	No. 1 Springer	NW NE NW 35, 18S-10W	3,273	SSC	1934	OKWSA
Rice	Nickerson et al	No. 1 Lyons	SE NW 27, 20S-8W	3,559	Petty	1935	OKWSA
Rice	Cities Service	No. 1 Heckel	NW NW SW 18 ,20S-9W	3,303	CSO	1934	CSO
Russell	Eldorado	No. 1 Strattman	SW SE SE 32, 14S-11W	3,210	SSC	1934	OKWSA
Russell	Empire	No. 1 Mai	C NW SW 24, 15S-14W	3,247	SSC	1934	OKWSA
Russell	Empire	No. 1 Ehrlich	NE NE SE 28, 13S-14W	3,274	GRC	1935	OKWSA
Scott	Atlantic	No. 1 Dague	C SW NW 14, 20S-33W	4,563	WGC	1935	OKWSA
Sedgwick	Empire	No. 1 Shawver	NE NE NE 13, 28S-2W	3,704	GRC	1934	OKWSA
Sherman	Sinclair-Pr.	No. 1 Mercer	NE NW 28, 10S-40W	5,868	SSC	1942	OKWSA
Stafford	Shell	No. 1 Schilling	C SW NW 26, 21S-13W	3,721	SSC	1934	OKWSA
Stafford	Rose Spring	No. 1 Toland	NW NW SE 2, 25S-14W	3,000	SSC	1935	OKWSA
Stafford	Stanolind	No. 1 Ray McComb	NE NE 27, 24S-11W	3,850	Stanolind	1938	
Stafford	Shaffer	No. 1 Newell	NE SE 20, 24S-11W	4,050	Stanolind	1938	
Stafford	Midwest Refg.	No. 1 Richardson	36, 22S-12W	3,509	GSI	1932	
Stafford	Atlantic	No. 1 Hohner	SE NE 31, 23S-14W	4,077	SSC	1935	
Sumner	Wentz-Conoco	No. 1 Kern	SE SE NE 6, 34S-2W	4,500	GSI	1934	OKWSA
Thomas	Texas	No. 1 Daugherty	NW SW SW 23, 6S-33W	5,023	Texaco	1943	OKWSA
Trego	Central Comm.	No. 1A Wagg	NW SE 17, 13S-21W	4,494	SSC	1936	SSC
			STATE OF LOUISIANA				
Acadia	Magnolia	No. 1 Duson	NE NE SW 14, 8S-2W	8,730	NGC	1937	Magnolia
Acadia	Union Sulphur	No. 1 Andrus	50, 8S-2E	9,490	GSI	1943	Un. Sulf.
Ascension	Humble	No. 18 Humble Comm.	30, 10S-2E	6,490	Neuman	1944	Magnolia
Assumption	Shell-Tidewater	No. 1 Michel	1, 14S-12E	10,940	Shell	1939	Shell
Beauregard	California	No. 1 Long Bell Lumber	C NE SW SE 23, 4S-9W	9,685	NGC	1939	Atlantic
Beauregard	Atlantic	No. 1A Rice Ld. & Lbr. Co.	22, 3S-11W	8,380	NGC	1939	Atlantic
Bienvill	Seaboard	No. 1 Magee					
Bossier	Crystal Oil	No. 1	7, 21N-11W	4,000	GRC		GRC

County	*Company*	*Lease*	*Location*	*Depth*	*Shot By*	*Date*	*Sponsored By*
Bossier	United Gas Pb.	Roos Unit	Sec. 14, T 17 N, R 12 W	4,971	SEI	1936	Union Prod.
Bossier	Prairie Rv. Syn.	Hutchinson	Sec. 15, T15N, R12W	7,315	SEI	1936	Union Prod.
Bossier	United Gas Pb.	Murff	Sec. 17, T17N, R11W	5,410	SEI	1936	Union Prod.
Bossier	United Gas Pb.	Henderson	Sec. 36, T17N, R12W	5,785	SEI	1937	Union Prod.
Caddo	Gulf	No. 1 Mrs. Hatcher	C SW SE 11, 17N-15W	8,160	GSI	1937	
Caddo	Stan. of La.	No. 1 Parker	CS/2 SE SW 9, 23N-16W	5,940	GSI	1937	
Caddo	R. W. Norton	No. 1 Hill	33, 23N-16W	3,970	GRC	1930	GRC
Caddo	Syndicate	No. 1 Hutchinson	SW SW NW 15, 15N-12W	7,315	SEI	1936	
Caddo	United Gas Pb.	Wheeler	Sec. 16, T18N, R16W	5,870	SEI	1936	Union Prod.
Caddo	United Gas Pb.	Gibson	Sec. 15, T23N, R16W	5,556	SEI	1935	Union Prod.
Caddo	United Gas Pb.	M. K. Smith	Sec. 33, T23N, R16W	5,690	SEI	1934	Union Prod.
Caddo	R. W. Norton	J. E. Payne	Sec. 27, T23N, R16W	11,260	SEI	1937	Union Prod.
Calcasieu	Hamman	No. 1 Sabine Rice Lands	3, 11S-11W	9,000	GSI	1940	Un. Sulf.
Calcasieu	Union of Calif.	Matilda Gray	Sec. 33, T10S, R12W	5,510	SEI	1942	Uuion Calif.
Caldwell	Ark. Fuel	No. 1 La. Central Lum.	C NW SW 31, 12N-3E	7,523	Ark. Fuel	1939	
Cameron	Texas Co.	No. 18 State	Hackberry D 12S-9W	9,208	Texaco	1941	Texaco
Cameron	Texas Co.	No. 29 State	Hackberry D 12S-9W	8,000	Texaco	1940	Texaco
Cameron	Magnolia-Humble	No. 35 Cameron Meadows Ld.	NW NE NE 35, 14S-13W	7,930	McCollum	1942	Magnolia
Claiborne	Stan. of La.	No. 1 Baker	C NW NW 27, 19N-7W	7,150	GSI	1937	Std. of La.?
Claiborne	Union Prod. Co.	McDonald Unit	Sec. 13, T21N, R3W	11,790	SEI	1942	Union Prod.
DeSoto	Benedum Trees	No. 1 Clifton	NE NW 33, 13N-12W	5,685	SEI	1935	Magnolia?
Franklin	Tensas-Delta	Paepcke	Sec. 22, T11N, R9E	6,413	SEI	1937	Union Prod.
Iberia		No. B1 State Vermilion	Ver. Bay D, 16S-5E	10,000	Texaco	1936	Texaco
Iberia	Texas Co.	No. 1 Jefferson Is.	Jeff. I. Bay D, 12S-3E	8,750	Texaco	1938	Texaco
Iberia	Texas Co.	No. 2 State	L. Fausse Pt. 11S-8E	5,683	Texaco	1936	Texaco
Iberia	Texas Co.	No. 1 Petit Anse Co.	Avery I. 59, 13S-6E	9,400	Texaco	1939	Texaco
Iberia	Texas Co.	No. B3 State	Ver. Bay D, 15S-5E	9,950	Texaco	1938	Texaco
Iberia	Texas Co.	No. 6 State	L. Fausse Pt. 11S-8E	5,400	Texaco	1939	Texaco
Iberia	Texas Co.	No. 7 Salt Mining Co.	Jeff. I. 12S-5E	7,500	Texaco	1941	Texaco
Iberia	Phillips	No. 1 M. & B.	Jeff. I. 12S-5E	9,750	Texaco	1939	Texaco
Iberville	Humble		Bayou Des Glaises	4,150	Humble	1939	
Jefferson	Texas Co.	No. 1 Rigollettes	Laffite 19, 17S-24E	9,372	Texaco	1935	Texaco
Jeff. Davis	Shell	No. 1 Lacassine Irrig.	NW SE SW 20, 11S-5W	9,350	Shell	1937	Shell
Jeff. Davis	Strake	No. 1 O. Miller et al	NW 7, 9S-5W	8,432	SEI	1936	Magnolia
Lafourche	Pan American	No. 1 Harang	SE/48, 17S-20E		Petty		
La Fourche	Gulf	No. 1 Grandison Land Co.	C NE NE 14, 20S-23E		Gulf		Gulf
La Fourche	Gulf	No. 3 La. State "PP"	Lat. 29°4.6′ N, Long. 90°17.1′ W		McCollum		Gulf
La Fourche	Helis-Gulf	No. 1 City of N. Orleans	Lat. 29°6′ N, Long. 90° 10.3′ W.		McCollum		Gulf
LaSalle	Phillips	No. 1 Tensas Delta	SE NE 1, 5N-4E	6,442	SEI	1941	Carter
LaSalle	Hunt & Ark. Fuel	Goodpine	Sec. 18, T10N, R3E	8,970	SEI	1940	Hunt Oil
Lincoln	Lide-Greer	No. 1 Gardner	SW NW NE 10, 17N-4W	6,341	GRC	1936	Amerada
Lincoln	Triangle Dr'lg.	Duback	31, 20N-3W	4,300	GRC	1934	GRC
Lincoln	Triangle Dr'lg.	No. 1 W. A. Colvin					
Madison	Murphy	No. 1 Sondheimer	10, 17S-12E	4,453	Petty	1944	Petty
Moorehouse	W. J. Furlong	No. 1 Clark	SE NW 10, 20N-7E	6,993	SEI	1938	Union Prod.?
Morehouse	Union Prod. Co.	Tensas-Delta	Sec. 9, T22N, R4E	10,400	SEI	1940	Union Prod.
Morehouse	Union Prod. Co.	Crossett T&D Unit	Sec. 6, T22N, R6E	6,951	SEI	1942	Union Prod.
Plaguemines	Texas Co.	No. 33 State	Garden I. 38, 23S-33E	6,635	Texaco	1939	Texaco
Pt. Coupe	Batchelor	No. 1 Hackney	SW NW 28, 3S-8E	9,979	Magnolia	1938	Magnolia
Rapides	Sid Richardson	No. 1 Weil	55, 1S-2E	8,613	GRC	1939	GRC

County	*Company*	*Lease*	*Location*	*Depth*	*Shot By*	*Date*	*Sponsored By*
Red River	Arkansas Fuel	No. 1 Franklin Realty	NE NW 20, 11N-9W	7,150	Ark. Fuel	1938	Ark. Fuel
St. Bernard	California	No. 1 Biloxi Marsh	NE SE 25, 12S-16E	9,500	GSI	1941	Calif.
St. Laundry	Texas Co.	No. 27 Botany Bay Lbr. Co.	Pt. Barre 6S, 5E	6,523	Texaco	1940	Texaco
St. Martin	Shell	No. 1 Iberville Land	86, 7S-8E	9,980	Shell	1939	Shell
St. Martin	Shell	No. 1 Frederick	38, 8S-5E	9,488	NGC	1938	Atlantic
St. Martin	Texas Co.	No. 6 St. Martin Land	17, 8S-7E	8,207	Texaco	1934	Texaco
St. Martin	Texas Co.	No. 7 St. Martin Land	9, 8S-7E	8,900	Texaco	1935	Texaco
Tensas	Carter	No. 1 H. Jacoby	C SE SE 34, 14N-11E	4,350	Petty	1942	Carter
Terrebonne	Texas Co.	No. 5 State	Coon Pt. 22S-17E	10,225	Texaco	1938	Texaco
Terrebonne	Texas Co.	No. 37 State	Lk. Barre 21S-19E	10,500	Texaco	1937	Texaco
Terrebonne	Texas Co.	No. B1 State	SE SW 19, 23S-20E	5,400	Texaco	1939	Texaco
Terrebonne	Texas Co.	No. B3 State	NE SE 13, 22S-17E	10,424	Texaco	1939	Texaco
Terrebonne	Shell	No. 4 E. L. Peters	72, 18S-18E	10,400	Shell	1940	Shell
Terrebonne	Humble	No. 1 Cont. Ld. & Fur.	Castell Area	10,250	Humble	1936	
Union	Stan. of La.	No. 1 Union Sawmill	NE SW 14, 21N-1E	9,982	Carter	1938	
Vermilion	Union of Calif.	No. 1 Gastinel	17, 15S-1E			1942	
Vermilion	Union & LL & E	No. 1C Louisiana Furs	33, 16S-2E	11,620	SEI	1942	Union
Vermilion	Magnolia	No. 1 Cormier	NE NE 5, 12S-2W	7,702	Magnolia	1939	Magnolia
Vernon	Shell	No. 1 La. Long Leaf Lbr.	15, 4N-9W			1942	
Vernon	Pan-American	No. 1 Anderson-Post	NE NW 27, 2N-11W	6,500	NGC	1939	Atlantic
W. Baton R.	Amerada	No. 1 Wilbert	SE 1/4 26, 7S-11E	9,952	Petty	1941	Petty
Webster	Tidewater	No. 1 Pipes	NE SE 10, 18N-10W	6,780	GSI	1938	
Webster	Magnolia	No. 5 Ira Cox	NW NW SE 23, 21N-10W	8,631	SEI	1937	Magnolia
Webster	Magnolia	No. 1 Sexton Unit	C S 1/2 32, 23N-9W	9,279	SEI	1938	
Webster	Ohio Oil Co.	No. 1 Coyle	NE SE 22, 21N-10W	8,100	GGC	1937	Ohio
			STATE OF MICHIGAN				
Clare	Gulf	No. 1 Marquette State	C S/2 SE NE 29, 19N-6W		Gulf		Gulf
Gladwin	Sun Oil Co.	No. 1 Tuckerman	W 1/2 NE NE 2, 17N-2W	3,530	IXC	1939	Sun
Midland	Andrews & Walters	No. 1 Harris	SW SW SW 14, 16N-1E	2,747	IXC	1939	Sun
Tuscola	Gulf	No. 1 Lassiter	NE SW SE 5, 13N-9E	4,138	Shell	1944	Shell
			STATE OF MISSISSIPPI				
Amite	J. L. Wimple	No. 1 Southern Forest Ld.	29, 4N-2E	5,200	GSI	1937	Calif.
Chickasaw	Carter	No. 1 (Strat Test)	12N-5W				
Clarke	Ark.-Miss. Co.	No. 1 Long Bell Lbr. Co.	C SW NE 35, 3N-17E	6,925	IXC	1940	IXC
Copiah	Carter	No. 1 Copiah Co. School	SE SE 16, 11N-5E	10,450	Carter	1943	Carter
Copiah	Sun Oil	No. 1 Ainsworth	NE SE 17, 9N-7E	9,675	Sun	1941	Sun
George	United Gas Pb.	Williams	Sec. 6, T1S, R5W	6,002	SEI	1935	Union Prod.
Givens		No. 1 Davis		6,590			
Greene	Humble	No. 1 Hurst		12,328	WGC	1944	Atlantic
Greene	United Gas Pub.	No. 1 Davis	30, 1N-5W	5,500	SEI	1934	Union Prod.
Greene	United Gas Pb.	School Board	Sec. 16, T1N, R5W	5,426	SEI	1935	Union Prod.
Hinds	Miss. Basin	No. 1 G. McLaurin	NW SW 17, 7N-2W	6,350	IXC	1939	IXC
Humphrey	Union Prod. Co.	Mattie Box	Sec. 15, T14N, R4W	4,800	SEI	1939	Union Prod.
Jeff. Davis	Courson et al	No. 1 Bailey	4, 6N-18W				
Lawrence	Tidewater	No. 1 Denkmann Lbr. Co.	C N/2 SW 5, 5N-11E	9,700	SEI	1941	SSWSA
Lincoln	California	No. 1 Smith	C NW NW 4, 7N-7E	12,050	GSI	1943	SSWSA
Madison	Carter	No. 1 Cooper	14, 11N-3E				Carter

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Madison	Union Prod. Co.	Anderson	Sec. 12, 8N, 1W	6,210	SEI	1939	Union Prod.
Monroe	Carter	No. 1 (Strat. Test)	22, 15S-6E	5,660	Carter	1941	Carter
Newton	Sun Oil	No. 1 Hilma Wall	NW NW 28, 5N-13E	10,098	Petty	1943	SSWSA
Pike	Pike Co. Oil Co.	No. 1 Causey	28, 3N-7E	3,800	GRC	1934	GRC
Rankin	Lion Oil Co.	No. 1 Mistérfield	2, 14N-1E	3,958	GRC	1929	GRC
Scott	E. L. Martin et al	No. 1 Adams Edgar Lbr.	C S/2 SW SE 25, 8N-6E	6,520	IXC	1940	IXC
Scott	Carter et al	No. 1 Newell Minerals	N/2 NW SW 32, 5N-7E	7,312	Carter	1942	
Sharkey	Br.-American	No. 1A Houston Estate	NE SW 23, 11N-7W	4,335	SEI	1941	Br.-Am.
Simpson	Carter	No. 1 Allison	C SW NW 17, 1N-4E	9,338	Carter	1943	Carter
Stone	H. I. Morgan	No. 1 Univ. of Miss.	C SE 35, 3S-10W	8,350	SEI	1941	SSWSA
Stone	Gulf	No. 6 Dantzler	CW/2 SW 22 4S-11W	6,200	Gulf	1934	Gulf
*Tallahatchie	Gulf	No. 1 Cason	C NE 2, 21N-1W		Gulf		Gulf
Wayne	Gulf	No. 1 Davis	C NE SE 2, 9N-9W		Gulf		Gulf
Yazoo	Sinclair Wyo.	No. 1 Swayze	SW SE NW 23, 12N-1E	6,510	Petty	1941	SSWSA
Yazoo	Conroe-Wilcox	No. 1 Stubblefield	NW NE SW NW 25, 12N-1W	5,568	IXC	1940	IXC
			STATE OF MONTANA				
Fallon	Montana-Dakota Utilities	No. 1 N. Pacific	SW NE NE 17, 4N-62E	8,110	SSC	1940	Carter
Pondera	Carter	No. 1 Pitcairn	NW SE 27, 28N-8W	4,914	WGC	1943	Gen. Pet.
			STATE OF NEBRASKA				
Boone	Carter	No. 1 (Strat. Test)	NE NE NE 23, 22N-7W	2,797	Carter	1941	Carter
Buffalo	Carter	No. 1 (Strat. Test)	SW SW SW 13, 10N-15W	4,060	Carter	1941	Carter
Buffalo	Carter	No. 1 (Strat. Test)	NE SE NE 27, 9N-13W	3,870	Carter	1942	Carter
Custer	Carter	No. 1 (Strat. Test)	SE 11, 18N-17W	3,460	Carter	1941	Carter
Dawson	Carter	No. 1 (Strat. Test)	NW NW NW 14, 10N-19W	3,952	Carter	1941	Carter
Frontier	Sinclair-Pr.	No. 1 Brown	21, 5N-29W	3,892	Petty	1942	Sinclair
*Grant	Byrd-Frost-Mag.	No. 1 Abbott	NE NE NW 22, 24N-38W	4,000	SSC	1936	OKWSA
Greely	Carter	No. 1 (Strat. Test)	SE SE SE 26, 18N-10W	3,277	Carter	1941	Carter
Phelps	Carter	No. 1 (Strat. Test)	C N 1/2 SE SE 15, 7N-20W	3,852	Carter	1942	Carter
Phelps	Carter	No. 1 (Strat. Test)	SW NW SW 9, 8N-18W	3,828	Carter	1942	Carter
Richardson	Pawnee Royalty	No. 1 Meyers	C NW NW 24, 1N-15E	3,650	SSC	1940	Phillips
Sherman	Carter	No. 1 (Strat. Test)	SW SW SW 19, 15N-14W	3,429	Carter	1941	Carter
			STATE OF NEW MEXICO				
Lea	Tidewater	No. 1L State	C NE NW 23, 12S-36E	5,200	IXC	1938	IXC
Lea	Brown	No. 1 State	4, 16S-35E				SSWSA
Lea	Marland	No. 1 Reed	22, 20S-36E	4,215	GRC	1930	GRC
Lea	Buell & Hagen	No. 1 State	33, 11S-35E	4,512	GRC	1930	GRC
Lea	Amerada	No. B4 State	29, 18S-38E	2,955	GRC	1930	GRC
Lea	Sinclair-Pr.	Jal Field			Petty	1935	Sinc.-Pr.
Lea	Repollo	No. 1 Hanagan	SE SW 12, 25S-36E	3,250	Petty	1934	Sinc.-Pr.
Roosevelt	Shell	No. 1 Harwood	C S/2 SE SE 27, 7S-35E	4,000	Shell	1939	Shell
Roosevelt	Sloan & Smith	No. 1 Lovern	4, 3S-35E	4,162	GRC	1929	GRC
			STATE OF NORTH DAKOTA				
Oliver	Carter	No. 1 Semling	C SE SE 18, 141N-81W	8,310	Texaco	1942	OKWSA
Williams	California	No. 1 Kamp	3, 154N-96W	9,975	GSI	1398	Calif.

STATE OF OHIO

County	*Company*	*Lease*	*Location*	*Depth*	*Shot By*	*Date*	*Sponsored By*
Mahoning	Magnolia	No. 1 Fields	Lot 19, T2, 1N-5W (Bersin)	4,700	Magnolia	1940	Mag.
Ashtabula	Magnolia	No. 1 Breyley	43, 11N-5W	3,330	Magnolia	1940	Mag.

STATE OF OKLAHOMA

Beaver	Anderson-Kerr	No. 1 Davis	C SW SE 36, 5N-26ECM	6,750	SSC	1936	OKWSA
Caddo	Denver P & R	No. 1 Sah Cam.	SE SE 33, 10N-10W	8,800	Petty	1936	OKWSA
Caddo	Sinclair-Pr.	No. 1 German	SW NW NW 1, 6N-13W	9,363	SSC	1940	OKWSA
Caddo	Amerada	No. 1 A. Smith	14, 10N-13W	7,890	GRC	1942	GRC
Caddo	Amerada	No. 1 Clift	30, 6N-10W	8,300	GRC	1943	GRC
Caddo	Magnolia	No. 3 White	25, 6N-10W	4,000	GRC	1931	GRC
Carter	Carter et al	No. 1 Williams	SW NE SW 27, 2S-3W	7,870	GRC	1936	OKWSA
Carter	Shell	No. 1 Smith	NW SE NE 30, 5S-1E	4,211	Shell	1937	Shell
Carter	Gulf	No. 8 Johnson	C SW SW 28, 2S-3W		Gulf		Gulf
Cimarron	Barnsdall	No. 1 State	C NW SE 35, 5N-5ECM	5,440	Stanolind	1938	OKWSA
Cleveland	Phillips	No. 1 Baker	C SE NW 11, 9N-2W	7,110	SSC	1934	OKWSA
Cleveland	Hall-Briscoe	No. 1 Crockett	C SW NW 33, 6N-1E	6,540	SSC	1942	OKWSA
Cleveland	Mid-Continent	No. 1 Collett	NE SW 35, 10N-1W	6,927	GRC	1934	OKWSA
Cleveland	Delaney et al	No. 1 Bugher	SE SE SW 12, 7N-2W	7,637	SSC	1938	
Coal	Amer.-Stanolind	No. 1 Travelers	SW NW SE 28, 1S-9E	4,467	GRC	1935	OKWSA
Coal	Carter et al	No. 1 Thompson	S/2 NE NW 34, 2N-9E	5,980	SSC	1935	OKWSA
Coal	Deaner-Moore	No. 1 Edwards	NW NE SE 27, 2N-8E	6,746	SSC	1934	OKWSA
Dewey	Magnolia	No. 1 Feikes	C SW SW 31, 18N-14W				
Garfield	Herndon Dr'lg.	No. 1 Allen Heirs	NE NE SW 35, 24N-3W	5,025	Petty	1935	OKWSA
Garfield	Amer.-Stanolind	No. 1 Brunken	SW SW NE 32, 23N-4W	5,870	GRC	1936	OKWSA
Garvin	Anderson-Kerr	No. 1 Rodke	NW NE NW 21, 4N-1W	4,708	GRC	1934	OKWSA
Gravin	Phillips	No. 1 Dennis	SE SE NE 7, 4N-1E	4,317	SSC	1934	Phillips
Garvin	Sinclair-Pr.	No. 1 Reed	SW SE NE 21, 3N-3E	3,074	Petty	1942	OKWSA
Garvin	McElrehth-Suggett	No. 1 Lasater	SE SE SW 2, 2N-1W	5,000	Petty	1936	OKWSA
Grady	Carter	No. 1 Harrison	C NW NW 28, 3N-5W	5,900	SSC	1934	
Grady	Gulf	No. 1 Thomas	SW NW NW 14, 4N-5W	0.050	Gulf	1937	OKWSA
Grant	Sultan Drlg. Co.	No. 1 Patton	SW SW SE 19, 29N-3W	3,219	SSC	1934	OKWSA
Grant	Helmerich-Payne	No. 1 Crouse	C NE SW 29, 25N-8W	6,434	GRC	1935	OKWSA
Grant	Shell	No. 1 Foster	NW NW SE 30, 27N-8W	6,125	GRC	1935	OKWSA
Harper	Sinclair-Pr.	No. 1 Neff	NW NW SE 21, 26N-24W	6,939	SSC	1934	OKWSA
Hughes	Stanolind	No. 1 Scruggs	NE NE 13, 9N-10E	3,300	GRC	1934	GRC
Hughes	Deep Rock	No. 2 Langford	NE SW NE 29, 7N-10E	3,817	SSC	1943	Deep Rock
Hughes	Deep Rock	Troupe-Moore	NW NW SE 11, 6N-10E	4,433	SSC	1944	Deep Rock
Jackson	Stanolind	No. 1 Gregory	C SE NW 36, 1S-24W	7,500	Petty	1942	OKWSA
Jefferson	Sinclair-Pr.	No. 1 Barrett	NW NW NW 31, 5S-6W	4,300	Petty	1936	OKWSA
Jefferson	Amerada	No. 1 Edminson	NW SE SW 28, 5S-8W	3,727	GRC	1928	GRC
Kay	Continental	No. 6 Hubbard	SE SE NE 12, 26N-2W	2,959	Conoco	1933	Conoco
Kay	Shell-Conoco	No. 4B McCormick	NW SW SE 29, 29N-1W	?	Shell	1939	Shell
Kingfisher	Black Gold	No. 1 Cole	SW NE 24, 18N-5W	Failed	Petty	1935	
Kingfisher	Jadeka	No. 1 Frakes	SW NW SW 16, 15N-6W	5,332	SSC	1934	OKWSA
Kingfisher	Phillips	No. 1 Grape	C NW SE 30, 18N-5W	7,820	Amerada	1940	OKWSA
Kingfisher	Anderson-Prit.	No. 1 Geis	C NE SW 15, 18N-9W	9,395	SSC	1940	OKWSA
Latimer	Limestone	No. 1 McMurry	12, 5N-18E	1,932	GRC	1928	GRC
Lincoln	Amerada-Stanolind	No. 1 Cavanaugh	SE SE NE 31, 15N-5E	4,565	GRC	1935	GRC

County	Company	Lease	Location	Depth	Shot By	Date	Sponsored By
Lincoln	Amerada	No. 1 Laffoon	NE SE NE 9, 13N-6E	3,950	GRC	1932	GRC
Lincoln	Stanolind	No. 2 Rice	11, 14N-3E	4,956	GRC	1934	GRC
Lincoln	T. B. Slick	No. 2 Kentzleman	SE SE SW 7, 14N-4E	4,800	GRC	1931	GRC
Lincoln	Twin-States	No. 1 Boland	SW SW SW 25, 12N-3E	5,290	GRC	1934	OKWSA
Lincoln	Texas	No. 1 Gessman	SE SE NE 33, 14N-4E	4,935	SSC	1934	OKWSA
Lincoln	Sinclair-Pr.	No. 1 Hoyt	NW SW NE 5, 14N-3E	4,971	SSC	1934	OKWSA
Logan	Amerada	No. 1 Fouts	NW NW NE 14, 17N-1W	5,020	GRC	1934	OKWSA
Logan	Gypsy	No. 2 Knowles	C SW NW 34, 17N-4W	6,055	SSC	1934	OKWSA
Logan	Anthony et al	No. 1 Fruin	SE SE SW 4, 16N-1E	5,180	SSC	1934	OKWSA
Logan	Gypsy	No. 1 Manning	NW NW NW 3, 17N-4W	?	SSC	1934	OKWSA
Logan	Summitt Drlg.	No. 1 Dunbar	SW SW NE 25, 15N-4W	6,410	Petty	1934	OKWSA
Logan	Sinclair-Pr.	No. 1 Koetsch	SW SW SW 23, 15N-3W	6,085	Petty	1935	OKWSA
Logan	Community	No. 1 Hirzel	SE SW SW 7, 16N-2W	6,006	Petty	1934	OKWSA
Logan	Big Chief Drlg.	No. 1 Trim	NE NE SE 13, 17N-2W	5,565	Conoco	1941	OKWSA
Logan	Continental	No. 3 Suits	SW SE NW 7, 17N-1W	5,475	GSI	1941	OKWSA
Logan	Texas Co.	No. 1 Wood	SW SW NE 34, 15N-4W	5,912	Texaco	1935	Texaco
Logan	Phillips-Barnsdall	No. 1 Seyller	NE NE SE 12, 15N-4W		Phillips	1934	Phillips
Logan	Carter	No. 1 Herren	SE NE 28, 17N-4W	5,957	Humble	1934	Carter
Logan	Helmrich-Payne	No. 1 Sturgiss	SE SE NW 1, 15N-2W	5,535	GRC	1935	GRC
Logan	Tidal Oil Co.	Tidal-Gardner	12, 19N-1W	2,909	GRC	1928	GRC
Logan	Eason	No. 1 Duck Club	NW NW NE 10, 16N-4W	5,500	GRC	1933	GRC
Logan	Healdton	No. 1A Gragg	SW SW SW 29, 18N-4W	6,058	GRC	1928	GRC
Logan	Prairie	No. 1 Sims	NE SW SE 22, 17N-1E	3,930	GRC	1931	GRC
Logan	Stan.-Amerada	No. 1 Nunn	SE SE NW 25, 15N-1E	5,220	GRC	1935	GRC
Logan	Shell	No. 1 Faulkner	C SE NW 11, 15N-4W	6,359	GRC	1935	GRC
Love	Sinclair-Pr.	No. 1 Stockton	SE SE SW 26, 6S-2W	6,871	Petty	1936	OKWSA
Marshall	Pure	No. 1 Quinton-Little "A"	C W/2 NE SE 28, 5S-7E	4,700	SSC	1940	OKWSA
McClain	Arab Pet.	No. 1 Autry	NW NW NW 16, 7N-3W	8,072	GRC	1936	OKWSA
McIntosh	Stan.-Ramsey	No. 1 Tiger	NW NW SW 13, 9N-15E	4,920	SSC	1936	OKWSA
McIntosh	?	No. 1 Patterson	32, 9N-16E	2,276	GRC	1928	GRC
Murray	Sinclair-Pr.	No. 1 Lancaster Trust	C SW NE 10, 1S-2E	2,950	Petty	1936	
Noble	Stan.-Amer.	No. 1 Kolb	NE NW 33, 20N-2W	4,000	GRC	1932	GRC
Noble	Barnsdall	No. 1 Miksch	NW NW SW 12, 21N-1E	4,900	GRC	1931	GRC
Noble	Deep Rock	No. 1 Blackhawk	C NW NE 21, 23N-2E	4,388	SSC	1942	Deep Rock
Noble	Deep Rock	No. 1 Schultz	NW NW SE 9, 22N-2E	4,749	SSC	1942	Deep Rock
Noble	Deep Rock	No. 1 Atkins	NW NW SE 25, 23N-1E	4,727	SSC	1943	Deep Rock
Noble	Superior-(Okla.)	No. 2 Faubian	NE SW SE 16, 22N-1E	4,728	GSI	1941	Sunray
Noble	Continental	No. 1 Bennett	SE SE NW 19, 20N-1W	5,115	SSC	1934	OKWSA
Noble	Gypsy	No. 2 Verna	C SE SE 29, 20N-2W	4,880	SSC	1934	OKWSA
Noble	Texas Co.	No. 1 Voss	SW NE SE 28, 22N-2W	4,285	GRC	1934	OKWSA
Noble	Magnolia	No. 1 Forsythe	SE SE SW 23, 21N-2W	5,360	Petty	1937	OKWSA
Noble	Berry & Bishop	No. 1 Wright	NE SW NW 1, 20N-1W		Stanolind	1943	
Noble	Carter	No. 1 Weber	C NE SW 20, 20N-2W	4,925	Humble	1934	
Okfuskee	Shell	No. 1 Smith	SW SE SW 26, 11N-8E		Shell?	1941	Shell?
Okfuskee	Lease Investment	No. 1 Lauder	SE SW SE 21, 13N-10E	3,540	SSC	1938	SSC
Okfuskee	Amerada	No. 1 Parsons	12, 11N-6E	4,410	GRC	1934	GRC
Okfuskee	W. C. McBride	No. 1 Replogle	NE NW SW 13, 11N-10E	2,160	SSC	1942	SSC
Oklahoma	Mid-Cont. et al	No. 1 Edwards	C SE SE 19, 11N-1E	5,955	Carter	1934	OKWSA
Oklahoma	Gypsy	No. 1 Shock	NW SW SW 2, 14N-3W	6,218	Petty	1935	OKWSA
Oklahoma	Stanol-Amerada	No. 1 Sueneram	NE NE NE 6, 13N-3W	6,250	GRC	1934	OKWSA
Oklahoma	Gypsy	No. 1 Shawbell	C SW NE 1, 12N-4W	5,920	Gulf	1933	

County	Company	Lease	Location	Depth	Shot By	Date	Sponsored By
Oklahoma	Springrose Drlg.	No. 1 Edwards	C SE SE 19, 11N-1E	5,955	Humble	1934	OKWSA
Okmulgee	Lease Investment	No. 2 Johnson	SW NE SW 4, 13N-11E	3,148	SSC		SSC
Okmulgee	Superior	No. 1 Gonseth	NE NE NW 7, 15N-12E	2,653	SSC	1934	SSC
Okmulgee	Lease Investment	No. 2 St. Cyr	28, 15N-11E	2,801	SSC		SSC
Pawnee	W. C. McBride	No. 1 Robedeaux	SE SW SW 30, 23N-3E	4,112	SSC	1942	McBride
Pawnee	Alma	No. 3 Robedeaux	C NW SE 26, 23N-3E	3,940	Ok. S. Co.	1942	Ok. S. Co.
Pawnee	Watchorn	No. 1 Harmon	C NE NW 29, 23N-4E	4,520	Ok. S. Co.	1943	Ok. S. Co.
Pawnee	Alma & Watchorn	No. 1 Reid	SE SW NW 1, 21N-6E		GSI		GSI
Payne	Midcontinent	No. 5 Ramsey	SW NW NW 18, 18N-2E	4,685	SSC	1938	OKWSA
Payne	Flynn	No. 1A Worth	NE SW NE 6, 19N-5E	3,710	SSC	1943	Stanolind
Payne	Marathon	No. 1 Potts	SW SW SW 27, 19N-2E	4,800	GRC	1935	GRC
Payne	Stan-Amer.	No. 1 Friedman	SE SE SE 28, 19N-3E	4,255	GRC	1935	GRC
Pontotoc	Carter	No. 2 Harden	NW NE SW 30, 2N, 7E	3,940	GRC	1935	GRC
Pott.	Phillips	No. 1 Ford	NE NE NW 17, 6N-3E	4,316	GRC	1934	OKWSA
Pott.	Atlantic	No. 1 School Land	C NW 36, 10N-4E	4,510	SSC	1933	
Pott.	Watchorn	No. 1 McCoy	NW NE SW 20, 6N-3E	4,162	Ok. S. Co.	1943	Ok. S. Co.
Pott.	Amerada	No. 3 Harrison	33, 7N-4E	3,900	GRC	1933	GRC
Pott.	Amerada	No. 1 Richardson	16, 7N-4E	4,097	GRC	1928	GRC
Pott.	Amerada	No. 1 Vineyard	NW NE NE 15, 7N-3E	4,683	GRC	1930	GRC
Pott.	Atlantic	No. 1 Honaker	6, 10N-5E	4,808	NGC		Atlantic
Seminole	Atlantic	No. 2 Damron	SE NE NW 22, 6N-6E	3,511	NGC	1938	Atlantic
Seminole	Amerada	No. 2 Block	SW SW NE 27, 8N-8E	4,117	GRC	1935	GRC
Seminole	Vivian	No. 1 Samedan-Reed	NW SW NE 6, 6N-8E	4,300	GRC	1934	GRC
Seminole	Sinc.-Pr.	No. 1 Harjo	Sec. 12, 5N-7E	4,217	Petty	1936	OKWSA
Seminole	Atlantic	No. 1 McCoy	SE NE NW 21, 7N-6E	4,375	NGC	1939	Atlantic
Seminole	Shell	No. 1 Smith	NE NE NE 4, 9N-7E		Shell		
Seminole	Wynona et al	No. 2 Fish	SE NW NE 30, 7N-8E				
Seminole	Amerada	No. 1 Ground	SE SW SE 23, 9N-5E	4,225	GRC	1929	GRC
Stephens	Carter	No. 1 McCasland	NW NW SW 22, 1S-4W	4,810	SSC	1934	OKWSA
Stephens	Skelly & Selby	No. 4 Robberson	C NE NE 35, 1S-5W	7,755	SSC	1941	OKWSA
Stephens	Gulf	No. 1 Springs	NW NW SW 16, 2N-7W	9,950	SSC	1944	OKWSA
Tillman	Gulf	No. 1 Wearmouth	SE NW SE 31, 1S-18W	4,400	Gulf	1936	OKWSA
Tillman	Magnolia	No. 1 Brown	C SW SE NE 21, 3S-18W	5,567	Petty	1937	OKWSA
Washita	Gulf	No. 1 Hopkins	C NW SE 8, 8N-20W	9,130	SSC	1943	OKWSA
Woods	Gulf	No. 1 Hess	C NE NW 33, 23N-13W	8,300	SSC	1941	OKWSA
Woodward	No. Ordnance	No. 1 Bradshaw	C SE SE 28, 22N-17W	10,031	SSC	1943	OKWSA
			STATE OF PENNSYLVANIA				
Potter	G. K. Rodgers	No. 1 Clair	Hebron Township	4,590	GRC	1933	GRC
			STATE OF SOUTH DAKOTA				
Stanley	Carter	No. 1 (Strat. Test)	9N-27E		Carter		Carter
			STATE OF TEXAS				
DISTRICT: EAST							
Anderson	TWA-Seaboard	No. 2 Monnig	Sanchez #1-11 Survey	4,040	GSI		
Bowie	Barnsdall	No. 1 Heilbron	M. H. Janes Sur.	7,060	NGC	1944	
Camp	Twa-Seaboard	No. 1 Roberts	O. Hendricks Survey	8,696	SEI	1944	Tidewater
Camp	Talco-Shell	No. 1 McKinsey	L. Williams Survey	7,800	Shell	1941	Shell

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Franklin	J. B. White	No. 1 Jackson	A-218, Hopkins Survey	8,785	Stanolind	1942	SSWSA
Franklin	TWA-Seaboard	No. 1 Gilbert	J. Macimillian Sur.	7,700	SEI	1943	
Franklin	Pure	No. 1 ?	Opelika Field	4,190	?	?	?
Freestone	Humble	No. 1 Dietz	Sanchez #6, A-33	5,280	Petty	1933	
Henderson	Black & Daly	No. 1 Meredith	W. Kay Survey	4,000	GRC	1934	GRC
Henderson	Roeser	No. 1 Billett	Cecil Bolo Sur.	4,127	GSI?		
Henderson	Pure	No. 1 Franklin	S. Hatton Survey	4,175	GSI		
Hunt	Stanolind	No. 1 Tilson Heirs	C. C. Dale Survey, A-240	4,420	Stanolind	1943	Stanolind
Hunt	Am. Liberty	No. 1 McNatt	A-647, Enos Murphy Sur.	6,875	Magnolia	1942	Magnolia
Hunt	C. D. Davis	No. 1 England	A-675 H. Marler Survey	5,000	Stanolind	1942	Stanolind
Limestone	Stanolind	No. 1 Norris	K. Thrasher Survey	8,725	SEI	1938	
Morris	Humble	No. 1 Wright	Samuel Story Sur.	9,000	Texaco	1944	SSWSA?
Nacogdoches	Texas	No. 1 Strahan	M. J. Arriola Survey	8,997	Texaco	1942	Texaco
Nacogdoches	Collier	No. A1 Mast	T. Lambert Survey	5,801	SEI	1937	Magnolia
Panola	Gulf	No. 1 Pierce et al	J. H. Shannon Survey	5,441	Texaco	1936	Texaco
Panola	United Prod.	No. 11 Werner	D. B. Lewis Survey	5,145+	GRC	1931	United Prod
Panola	Magnolia	No. 1 Hull	T. Applewhite Sur.	5,799	SEI	1937	Magnolia
Rains	Humble	No. 1 O. L. J. Easter	R. Hotchkiss Survey	8,195	Humble	1937	
Rusk	Texas	No. 1 Christian	Setton Survey	7,111	Texaco	1943	SSWSA
Smith	Amerada	No. 1 Christian	Felix Flores Sur.	5,341	GRC	1929	GRC
Tyler	Houston	No. 1 Stern Fee	A. Stern Sur.	4,700+	GRC	1932	GRC
Upshur	Amerada	No. 1 Wade	Henry Field Sur.	4,325	GRC	1929	GRC
Van Zandt	Delta	No. 1 Gipson-Echols	J. Walker Sur., A-902	8,845	Stanolind	1944	
District: Gulf Coast & South							
Aransas	Atlantic	No. 1A Porterfield		7,100			
Atascosa	Henderson-Coquat	No. 1 Beshears	A-194 Loving Survey	5,800	GSI	1941	
Bee	Stanolind	No. 1 Gould	W. C. Gill Surv. A-166	9,486	Stanolind	1942	SSWSA
Bee	Hewitt-Dougherty	No. 1 Weiss	Jose Uranga Grant	9,850	SEI	1941	SSWSA
Bee	McBride & Rowe	No. 1 Faktor	G. Garcia Survey	4,743	Petty	1941	Petty
Brazoria	Texas Co.	No. 5 Freeport Sulfur	S. W. Frank Bryan Mound	3,282	Texas	1938	Texaco
Brazoria	Rycade	No. 1 Rapid City	A-10, H. Austin Sur.	5,640	GRC	1930	GRC
Brazoria	Slade	No. 1 Peach Point					
Brazoria	Amer.-Rycade	No. 3 Seaburn	Austin Williams Sur.	4,409	GRC	1933	
Brazoria	Humble	Bassett-Blakely		7,500	Humble	1940	
Brooks	So. Minerals	No. 1 Proctor	Sec. 20 Los Olmos & Loma Blanco	7,600	NGC	1939	Atlantic
Burleson	Blumenthal	No. 1 Crain	W. C. Pearce Sur.				GSI
Chambers	Texas Co.	No. 1 Broussard	Sec. 94, A-426	9,100	Texaco	1941	Texaco
Chambers	So. Gulf	No. 1 White	Luke Bryon Sur.	7,616	SEI	1935	
Colorado	Magnolia	No. 1 Anderson	Sec. 15, G.H.&H. RR Sur.	8,850	Magnolia	1943	SSWSA
DeWitt	Atlantic	No. 1 Conwell	C. Lockhart Survey	9,680	NGC	1940	Atlantic
Duval	Atlantic	No. 1 Gravis	Sec. 88, SA&MG RR Sur.	5,750	NGC	1938	
Ft. Bend	Magnolia	No. 1 Huntington	Henry Scott League	8,121	Magnolia	1939	Magnolia
Ft. Bend	Gulf	No. 53 Moore	F. Frazier Tr., M. Young Lge.		Gulf		Gulf
Frio	Amerada	No. 1 Oppenheimer	W. F. Halsell Sur.	6,270	GRC	1932	
Frio	Amerada	No. 2 Oppenheimer	J. H. Gibson Survey	8,500	GRC	1934	
Frio	Humble	Houston		5,150	Humble	1939	
Galveston	Atlantic	No. 3 Roberts	P. G. Merritt Survey	7,400	NGC	1937	Atlantic
Galveston	Shell	No. 1 Maco Stewart	J. Spillman No. 1 Sur.	9,100	Shell	1937	Shell
Galveston	Mid-States	No. 1A Maco-Stewart	Div. 7 Perry Austin Sur.	9,311	SSC	1938	Phillips

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Galveston	Humble	No. 1 Rosenkrantz		5,600	Humble	1933	
Goliad	Frazier & Taylor	No. 2 Bunte et al	W. R. Smith Survey	5,550	NGC	1938	Atlantic
Gonzales	Randon Prod.	No. 1 Dunning					
Grimes	Magnolia	No. 1 Brigance Est.	Richard Ray Survey	8,862	Magnolia	1942	Magnolia
Hardin	Atlantic	No. 1 Rogers	Batson Salt Dome	5,590	NGC		Atlantic
Hardin	Houston	No. 1 Ariola Fee	Ariola Survey	2,500	GRC	1932	
Harris	Union Prod.	No. 1 Goodykoontz	W. S. Powell Sur.	7,450	SEI	1938	
Harris	Stan. Amerada	No. 1 Nelson	A-34, J. House Survey	5,475	GRC	1934	
Harris	Stan. Amerada	No. 1 Bode	A-375 John Hooper	4,000	GRC	1934	
Harris	Hill & Hill	No. 1 Wharton	Blk. 1 W C.R.R. Survey	7,150	GRC	1935	
Harris	Magnolia	No. 1 Martens		6,950	Humble	1933	
Harris	Texas Gulf	No. 1 Gillespie	S. Contreras Sur.	6,930	SEI	1937	
Hidalgo	Texas Co.	No. 1 Rich	San Ramon Grant	7,500	Texaco	1944	Texaco
Hidalgo	Sun	No. 2 Saenz	S. Bazan Survey	4,610	Sun	1940	Sun
Houston	Shell et al	No. 1 Darsey	Marselina Salas Survey	9,850	Shell	1940	
Jackson	Magnolia	No. 2 West	A-59, R. Musquez Sur.	5,653	Magnolia	1938	Magnolia
Jefferson	Magnolia	No. 1 Phelan	S. Stivers Sur.	8,405	IXC	1937	Magnolia
Jefferson	Sun	No. 1 Long	J. Blair Survey	8,100	GRC	1935	GRC
Jefferson	Humble	No. 1 McFaddin State		2,603	Humble	1938	
Jefferson	Humble	No. 2 McFaddin State		2,125	Humble	1938	
Jefferson	Gulf	No. 1 Spencer-Junker	W. H. Smith Survey		Gulf		Gulf
Jim Hogg	Humble	No. 1 Mestenia	Jones Ranch	6,818	Humble	1939	
Jim Wells	Magnolia	No. 9 Seeligson	Los Jaboncillos Grant	6,500	Magnolia	1938	Magnolia
Kenedy	Humble	No. 2 Kenedy		7,650	Humble	1939	
Kenedy	Humble	No. 3 Kenedy		7,700	Humble	1939	
Kleberg	Magnolia	No. 1 Dietz	Gabriel Trevino Sur.	7,475	IXC	1938	Magnolia
Lee	Pederson	No. 1 Brown	David Hudson Sur.	7,900	Shell	1940	Shell
Liberty	Gulf	No. 115 Phoenix	Jesse Devore Survey		Gulf		Gulf
Matagorda	Texas Co.	No. 1 Pierce	A-209, H&GN Survey	8,963	Texaco	1940	Texaco
Matagorda	Sun	No. 1 Bay Shore Farms	Sec. 9 TRD Sub'd.	8,500	NGC	1937	Atlantic
Matagorda	Cities Service	No. 1 Duffey	Lot 13, J. W. E. Wallace Survey	9,200	Petty	1941	Petty
Matagorda	Humble	No. 1 Pierce Estate		6,800	Humble	1932	
McMullen	Quintana & Humble	No. 1 Grimes	Blk. 10, Wm. Hermitage A-1026	7,496	Petty	1943	
McMullen	Quintana	No. C8 S. Tex. Syndicate	Blk. 19, B. S. & F. Sur. A-88	6,416	Petty	1944	
Montgomery	Rycade	No. 2 Drought	John Conkright Survey	4,200	GRC	1933	
Nueces	United Production	No. 2 Walton	Matias Garcia Survey	4,760	SEI	1936	Union Prod.
Nueces	United Production	No. 1 Golladay	Sec. 1, Garcia Grant	8,150	SEI	1938	Union Prod.
Nueces	Renwar	No. 1 Eshberger	Sec. 2, Blk. 5, De. Herrara Sur.	7,279	Shell	1939	Shell
Orange	Texas Co.	No. 11 Kuhn	Pt. Neches Field	5,730	Texaco	1935	Texaco
Orange	United Pub. Ser.	No. 1 Moore	J. Dyson League	6,092	SEI	1937	Union Prod.
Polk	Shell	No. 1 Doucette	"Ace" Area, Sublette Survey	8,400	Shell	1939	Shell
Polk	Marathon		near Livingston	?	?	1933	
Polk	Sunshine	No. 2 Bates	A. Viesca Survey	2,800	GRC	1932	
Polk	Wood	No. 1 Tex. Long L. Lbr.		4,402	Petty	1941	
San Patricio	Porter Dr'lg.	No. 1 Schmalsteig	Sec. 9, F. P. Co. Lands	6,500	NGC	1937	Atlantic
San Jacinto	Shell	No. 1 Turner	K. Holliday Sur. A-157	11,801	Petty	1943	
Starr	Rowan & Hope	No. 1A Guerra	A. Farias Survey	4,531	Magnolia	1938	Magnolia
Starr	Transwestern	No. 1 Dallas J. S. Land Bk.	Sec. 226	5,000	Petty	1938	
Trinity	Magnolia	No. 1 Cameron	Henry Bond Survey	7,300	Magnolia	1941	Magnolia
Victoria	Frazier et al	No. 1 Booth	Fordtram Area	9,100	Texaco	1940	Texaco

County	*Company*	*Lease*	*Location*	*Depth*	*Shot By*	*Date*	*Sponsored By*
Walker	Hogg Bros.	No. 1 Gibbs Bros. et al	C. W. Stewart Survey	7,947	Petty	1941	Petty
Washington	Sunray et al	No. 1 Lockhart	G. Kuykendall Survey	7,450	Shell	1939	Shell
Webb	Magnolia	No. 1A Hamilton Ranch	Joaquin Galan Grant	9,177	Petty	1941	Petty
Wharton	Texas Co.	No. A26 Pierce Estate	Pickett Ridge Field	4,700	Texaco	1936	Texaco
Wharton	Texas Co.	No. 17 Taylor	Boling Dome	5,100	Texaco	1938	Texaco
Wharton	Texas Co.	No. B30 Pierce Estate	Withers Field	5,534	Texaco	1939	Texaco
Willacy	Shell	No. 1 Yturria	Sh. 64, S. J. deCarricitos	7,500	Shell	1937	
Wilson	Humble	No. 1 Hardy	J. Reynolds Survey	4,518	GRC	1938	
Zapata	Geo. Echols	No. 1 Volpe	Porcion 32			1943	
DISTRICT NORTH							
Archer	J. K. & L. Dr'lg.	No. 1 Ford	A-982, T. Cecil Sur.	4,050	Shell	1938	OKWSA
Archer	Humble et al	No. 1 Fuller	Blk. 1 H & TC A-926	4,990	IXC	1938	IXC
Clay	Shell	No. 1 Davis	Blk. 93 Belcher Sur.	5,992	Shell	1940	OKWSA
Clay	Continental	No. 2 Earl Spring	Blk. 4, A-247 H & TC RR	5,578	SSC	1942	Conoco
Clay	Continental	No. 1A Stephens	A-449, Stipps Survey	6,122	Conoco	1944	Conoco
Cooke	Sinclair	No. 1 Cory	A. Horton Sur., A-443	6,223	Petty	1944	OKWSA
Cooke	Texas Co.	No. 1 Rasure	J. Massingill Sur. A-687	6,775	IXC	1944	Texaco
Denton	Amon Carter	No. 1 Allen	S. Westbrook Sur. A-1337	8,985	Gulf	1941	
Foard	Texas Co.	No. 10 Johnston	Sec. 36, Blk. L	3,606	Texaco	1935	Texaco
Foard	Texas Co.	No. 1 Nichols	Sec. 298, Blk. A, H&TC	5,064	IXC	1943	SSWSA
Grayson	Tex-Talbert	No. 1 Jewell	Coryell Survey				
Hardeman	Amerada	No. 1 Rice Estate	Blk. H. A-412 Sec. 81	8,096	GRC	1939	OKWSA
Haskell	Forest Dev. Co.	No. 3 Pardue	M. Column Sur. Sec. 4	5,290	GRC	1938	GRC
Haskell	Amerada	No. 1 Kleiner	Blk. 57, J. McCass Sur.	5,600	GRC	1939	GRC
Jack	Shell	No. 1A Carter	Blk. 3311, TE&L Sur.		Shell	1942	Shell
Jack	Hanlon-Buchanan	No. B1 Hoefle	A-318, A. James Sur.	4,900	GSI	1941	GSI
Jack	Continental	No. 1 Sewell	A-304, Wm. Montry Sur.	5,916	Conoco	1944	Conoco
Jack	Continental	No. 1 Risch	Sec. 13, Henderson Co. S. L.	6,402	Conoco	1944	Conoco
Jack	Atlantic	No. 1 Fee	Wm. Wilkins, Survey	3,168	NGC	1944	
Lamar	Gant-Conoco	No. 1 Brown	G. E. Nabours Sur.	7,290	Sanolind	1940	OKWSA
Montague	Gibson-Jennings	No. 4 Howard	Blk. 90, Kaufman School	4,027	SSC	1940	OKWSA
Montague	Hammond et al	No. 1 Jester	A-835, F. Wingate Sur.	6,495	Gulf	1941	
Montague	Continental	No. 1 Hundley	D. Martindale Sur.	7,780	Conoco	1944	Conoco
Montague	Continental	No. 1 McNutt	Sec. 38, ETRR Survey	6,990	Conoco	1944	Conoco
Tarrant	B. Sullivan	No. 1 Putnam	M. Gilbert Sur.	7,775	Stanol.	1941	
Wilbarger	Texas	No. 1 Main	Blk. 8, HTCRR Sur.	4,700	IXC	1943	SSWSA
Young	Shell	No. 2A Bullock	Sec. 343, TE&L			1942	
Young	And.-Prichard	No. 1 Lattimer et al	Blk. 17, Young Co. S. L.	3,591	Shell	1943	Shell
Young	A. T. Strong, et al	No. 1 Weaver	Sec. 2950, TE&L Survey	4,800	GSI	1940	?
DISTRICT: PANHANDLE							
Carson		No. 1 J. E. Griffin	Sec. 9, Blk. 2, ABM Sur.			1942	
Donley	Stanolind	No. 1 Broome	Sec. 46, Blk. 20 H & GN Sur.	6,716	Texaco	1944	SSWSA
Donley	Shamrock	No. 1 Adair	Sec. 15, A451, GS&SFRR		IXC	1944	SSWSA
Donley	Robinson & Jones	No. 1 Kuteman	Sec. 88, Blk. 20, H&GNRR Sur.	4,100	Stanolind	1939	
Potter	Sinclair-Pr.	No. 1 Bush	Sec. 23, Blk. 6, BS&F Sur.	6,132	Stanolind	1939	
DISTRICT: WEST							
Andrews	Phillips	No. 1 University	Sec. 32, Blk. 10 U.T.L.	7,468	Stanolind	1941	Stanolind

County	*Company*	*Lease*	*Location*	*Depth*	*Shot By*	*Date*	*Sponsored By*
Andrews	Shell	No. 1 Cox	Sec. 5, Blk. A-31, P.S.L.	11,057	Shell	1944	Shell
Andrews	Atlantic	No. 1A Texas Univ.	Sec. 9, Blk. 12 Univ. Ld.	10,678	Texaco	1942	SSWSA
Andrews	Texas Co.	No. 1H Univ. of Texas	Sec. 4, Blk. 14, U.T.L.	4,846	NGC	1938	
Andrews	York & Harper	No. 1 Hereford Stock Farms	L. 12, Lg. 315, Palmer S.L.	4,925	WGC	1935	
Andrews	Humble	No. 1 Kuykendall		4,086	Humble	1934	
Andrews	Deep Rock	No. 2 Harris	Blk. A-46, Sec. 20	2,900	GRC	1930	GRC
Andrews	Humble	No. 3 Means	Sec. 9, Blk. A-35	3,905	Humble?	?	
Bailey	Illinois Oil	No. 1 Yellowhouse	NE/4 Labour #4, Blk. 700	4,440	WGC	1937	Stanolind
Briscoe	Phillips	No. 1 Montague	Sec. 6, Blk. 4, ABM Sur.	8,150	Texaco	1941	Texaco
Crane	Texas	No. 1 Frazer	Sec. 19, Blk. 42, T4S, T&P.RR	6,209	Texaco	1942	SSWSA
Crane	Loffland Bros.	No. 3 Tubbs	Sec. 9, Blk. B-27, P.S.L.	5,800	NGC	1937	Atlantic
Crane	Magnolia	No. 21 Lea	Sec. 16, Blk. 32, P.S.L.	6,500	Magnolia	1943	Magnolia
Crane	Gulf	No. 1 Waddel et al	Sec. 4, Blk. B-27, P.S.L.	5,800	GSI	1936	
Crockett	Moncrief et al	No. 1 Couch	Sec. 30, Blk. QR, G.C. & S.F.RR	6,500	Stanolind	1942	Stan. of T.
Crockett	J. H. Hughes	No. 1B Hughes-Powell	Sec. 63, E.L.&R.R. Sur.	2,624	GRC	1927	GRC
Crockett	Amerada	No. 1A Todd	Sec. 25, Blk. W, G.C.&S.F.RR	6,135	GRC	1941	GRC
Crosby	Gulf	No. 1C Swenson	Sec. 95, Blk. 2 H&GN.RR	8,400	Gulf	1940	
Dawson	Albaugh	No. 1 Robinson	Sec. 46, Blk. M	4,400	WGC	1935	
Dickens	Humble	No. 1 Matador Ranch		7,030	Humble	1939	
Ector	Stanolind	No. B1 Cowden	Blk. 44, TIN, T&P.RR	6,980	WGC	1941	
Ector	Atlantic	No. 2C Cummins	Sec. 24, Blk. 45, TIN, T&P. RR	4,035	NGC	1937	Atlantic
Fisher	General Crude	No. 6 Willingham	C NE SE Sec. 207, Blk. 1	3,081	Petty	1936	
Gaines	Texas	No. 1 Robertson	Sec. 25, A-21, PSL	7,687	Texaco	1942	SSWSA
Gaines	Stanolind	No. 15 Amer. Warehouse	Sec. 5, Blk. H	11,922	Stanolind	1943	Stanolind
Gaines	Gill-Honolulu	No. 1 Simpson	Sec. 8, Blk. C-44, PSL	5,266	NGC	1937	Atlantic
Gaines	York & Harper	No. 1 Jones	Sec. 414, Blk. G	4,900	WGC	1936	
Gaines	Stanolind	No. 5 Johnson	Sec. 6, Blk. H, D&W RR	4,850	WGC	1942	
Gaines		No. 1 Gill-Crews	Sec. 9, A-20, PSL	6,300	GRC	1934	GRC
Garza	Gulf	No. 1 Swenson	Sec. 25, Blk. 2, H&GNRR	8,090	Gulf	1938	
Glasscock	Moore et al	No. 1 McDowell	Sec. 22, Blk. 34, T&P RR	9,350	GRC	1935	GRC
Hale	Humble et al	No. 1 Byrd	Sec. 17, Blk. K, TTRR Sur.	6,745	Stanolind	1941	Stanolind
Hockley	Texas Co.	No. 1 Slaughter	Sec. 83, L38, Zavalla Co. S.L.	5,023	Texaco	1937	Texaco
Irion	Humble	No. 2B Sawyer	Sec. 3, Coulson Survey	9,495	NGC	1944	
Irion	Shell	No. 1 Tankersley	Sec. 12, G.C. & S.F. RR Sur.	8,000	NGC	1944	
Lamb	Stanolind	No. 1 Hopping	Sec. 25, Blk. T., Thompson Sur.	9,350	Stanolind	1942	Stanolind
Loving	T. P. Coal & Oil	No. 1 Carmine	Sec. 40, T1, Blk. 54	3,690	GSI	1934	
Lubbock	Livermore	No. 1 Moxley	Sec. 64, Blk. 20, H.E.&WT.RR	3,375	Texaco	1942	
Martin	Magnolia	No. 1 Teague	Labor 10, Lge. 260, Borden C.S.L.	6,631	Petty	1941	Petty
Martin	Gulf	Core Test	Sec. 42, Blk. 6, Tex. U. S.L.		Gulf		
Pecos	Humble	No. 1 White & Baker		8,800	Humble	1934	
Pecos	Humble	No. 1 Young	Sec. 33, Blk. 10, H&GN.RR	7,300	Shell	1940	Shell
Pecos	Phillips	No. 1 Price	Blk. 101, TCRR Survey, Sec. 11	15,014	SSC	1944	Phillips
Reeves	Kitsos & Scott	No. 1 Burchard	Sec. 7, Blk. 58, PSL	3,700	NGC	1942	Stan. Tex.
Reeves	Stan. of Tex.	No. 1 Keasler et al	Sec. 10, Blk. 72, PSL	8,891	GSI	1944	Stan. Tex.
Regan	Skelly	No. 1D Grayson	Sec. 33, Blk. 8	8,000	GRC	1935	GRC
Sterling	Gulf	No. 1C Foster	Sec. 28, Blk. 12, SPRR	8,050	Gulf	1942	Gulf
Stonewall	Shell	No. 1 Patterson	Sec. 393, Blk. D, H&TC.RR	6,660	Shell	1940	Shell
Stonewall	Leader	No. 3 Carlile	Sec. 293, Blk. D H&TC	6,573	SSC	1941	Leader
Terry	Pickens et al	No. 1 Lewright	Sec. 1, Blk. C-37, PSL	4,948	WGC	1937	Stanolind

County	*Company*	*Lease*	*Location*	*Depth*	*Shot By*	*Date*	*Sponsored By*
Upton	Amerada	No. 3 Hughes	Sec. 4, Wm. Teer Sur.	2,150	GRC	1927	GRC
Upton	Gulf	No. 103 McElroy	Sec. 197, Blk. F	8,200	GRC	1935	GRC
Upton	T.P. Coal & Oil	No. 52A Lane	Sec. 5, G.C.&S.F. Sur.	8,300	Stanolind	1943	
Winkler	York & Harper	No. 1 Gunter-Munson	G.M.M.B.&A. Survey, Blk. C, Sec. 7	4,997	SSC	1937	
Winkler	Stan.-Shell	No. 1 Blue	Sec. 15, Blk. 46, T & PRR	9,300	Stanolind	1943	SSWSA
Winkler	Magnolia	No. 130 Walton	Sec. 15, Blk. B-3, PSL.	3,045	Magnolia	1938	Magnolia
Winkler	Amon Carter et al.	No. 2C Walton	Sec. 1, Blk. B-3, P.S.L.		Gulf		Gulf
Yoakum	Bahago-Bond	No. 1 West	Sec. 607, Blk. D, Gibson Sur.	5,375	Gulf	1938	
Yoakum	Gulf	No. 1 Dixon	Sec. 609, Blk. D, Gibson Sur.	4,662	Gulf	1938	
Yoakum	Honolulu	No. 1 Kendrick	Sec. 825, Blk. D. Gibson Sur.	4,412	IXC	1938	Tidewater
Yoakum	Stogner & Pipkin	No. 1 Blades-Pollard	Sec. 103, Blk. D, Gibson Sur.	4,470	NGC	1938	
			STATE OF UTAH				
Grand	Utah Southern	No. 1 Hyde	NW 33, 22S-22E	4,880	CGC	1936	CGC
			STATE OF WEST VIRGINIA				
Lewis	Hope Nat. Gas	No. 8555 Woofter	Albert Woofter Farm	6,940	Petty	1941	Hope
Monongalia	Hope Nat. Gas	No. 8526 Greer	Mannington Working Dist.	7,684	Petty	1941	Hope
			STATE OF WYOMING				
Albany	California	No. 2 Holst	13, 17N-77W	3,226		1935	
Fremont	Sinclair-Wyo.	No. 2 Muskrat "C"	NE SW NW 1, 33N-92W	6,460	SSC	1936	OKWSA
Laramie	Amerada	No. 1 Morton	C SW SW 13, 13N-66W	6,700	GRC	1936	GRC
Natrona	General Pet.	No. 1 Government	21, 35N-77W			1938	
			FOREIGN COUNTRIES				
			CANADA				
Alberta	Dominion	No. 1 Wrentham Province	Sec. 2 T6-R17W 4th	3,273	GSI	1943	
Alberta	Dominion	No. 1 Chin Province	LSD 13, Sec. 11, T8-R18W 4th	3,509	GSI	1943	
Alberta	Mid-Cont.	No. 1	LSD 10, Sec. 12, T8-R17W 4th	3,309	GSI	1943	
Alberta	S.O.B.C.	No. 1 C.R.R. Princess	LSD 13, Sec. 22, T20-R12W 4th	3,248	GSI	1939	
Alberta	S.O.B.C.	No. 1 Tide Lake Prov.	LSD 9, Sec. 19, T18-R9W 4th	4,123	GSI	1940	
Alberta	S.O.B.C.	No. 1 Taber Province	LSD 9, Sec. 18, T9-R16W 4th	3,270	GSI	1942	
Alberta	S.O.B.O.	No. 1 Eyremore C.P.R.	LSD 4, Sec. 24, T18-R17W 4th	4,700	GSI	1942	
Alberta	Imperial	No. 5 NW Tilley	SW SE SW 17, T17-R12W 4th	3,238	Carter	1942	Carter
Alberta	Imperial	No. 1 Rolling Hills	SE SE 10-T14-R14W 4th	3,194	Carter	1942	Carter
Alberta	Imperial	No. 1 Arca	NE NE NE 24-T18-R1W 5th	6,520	Carter	1936	Carter
Alberta	Imperial	No. 2 Rainy Hills	SE SE SE 23-T18-R11W 4th	3,400	Carter	1941	Carter
Alberta	Royalite	No. 1 Wildcat Hills	Lsd. 16, Sec. 30, T27N-R5W, 5th.		Heiland	?	?
Alberta	S.O.B.C.	No. 1 Ross Lake Province	C Lsd. 4, Sec. 17, T2N-R22W, 4th		Heiland	?	?
Alberta	Shell of Canada	No. 1 Snider	C Lsd. 16, Sec. 34, T19N-R29W, 4th		Heiland		
Alberta	Shell of Canada	No. 1 McWilliam	Lsd. 8, Sec. 1, T21N-R26W, 4th		Heiland		Shell
Alberta	Shell of Canada	No. 1 Norman	Lsd. 5, Sec. 22, T24N-R5W, 5th		Heiland		Shell
Saskatchewan	Norcanols	No. 1 Radville	NE NE NE 36-T5-R19W 2nd	5,770	Carter	1942	Carter

County	*Company*	*Lease*	*Location*	*Depth*	*Shot By*	*Date*	*Sponsored By*
			COLOMBIA, SOUTH AMERICA				
Bolivar	Socony-Vacuum	No. 2 Cimitarra	Cimitarra Concession	5,386	IXC	1943	So.-Vac.
Colombia	Colombia Pet.	No. 1 Socuavo	Barco Concession	8,890	Petty	1941	
Magdalena	Shell	No. 1 Todos Los Santos	Magdalena	2,780 m.	?	?	?
Magdalena	Richmond Pet.	No. 1 El Retiro	6 Km. N.W. of El Doce	940 m.	GSI	1943	?
Santander	Socony-Vacuum	No. 1 Narino	Restrepe Concession	4,435	IXC	1939	So.-Vac.
Santander	Socony-Vacuum	No. 1 McCarthy	McCarthy Concession	5,428	IXC	1942	So.-Vac.
Santander	Shell	Zambito	Consorcio Minero Concession	2,300	Shell	1939	So.-Vac.
			SOUTH IRAN				
Inquire of Anglo-Iranian Oil Co. (about 6 wells surveyed)					SSC	1938	
			MEXICO				
Tabasco	Jalpa	No. 1 ?	?	2,080M			
			NETHERLANDS EAST INDIES				
New Guinea	N.N.G.P.M.	No. 1 Wassian	?	1,480M	GSI	?	
Bantam Java	N.V. Pet. Maatschapij Sadjira	No. 1 Sampang	Near Rangkasbitoeng, Java	6,170	GSI	1938	
Borneo	Ned. Koloniale Pet.	No. 1 Kahajan	Garoeng Village S. E. Borneo	3,280	NKP	1938	Carter
			SUMATRA				
	Ned. Koloniale Pet.	No. 2 Ogan	Res. Palambang	2,800	NKP	1938	Carter
	Ned. Koloniale Pet.	No. 3 Ogan	Res. Palambang	4,542	NKP	1939	Carter
			VENEZUELA				
?	?	No. 1 Guayabo	?	4,202	?	?	?
?	?	No. 1 El Machete	?	3,222	?	?	?
Anzoategui	Gulf	No. 2 Tigre	District of Freitas		Gulf		Gulf
Anzoategui	Gulf	No. 2 Merey	District of Freitas		Gulf		Gulf
Anzoategui	Gulf	No. 7 Oficina	District of Freitas		Gulf		Gulf
Anzoategui	Socony-Vacuum	No. 6 Guario	Distro Aragua (Origin:—Plaza Bolivar Barcelona)		SSC		So. Vac.
Anzoategui	Socony-Vacuum	No. 1 Los Pobres	Distro Monagas (Origin:—Barcelona)		SSC		So. Vac.
Guarico	S.A. Petrolera Las Mercedes	No. 7 Las Mercedas	Distro Infante (Origin:—Valle de la Pascua)		SSC		
Guarico	S.A. Petrolera Manapire	No. 1 Manapire	N 166, 471.43—E 173, 969.72 (Origin:—Valle de la Pascua)		SSC		
Monagas	Creole	No. 1 La Cruz	Distro Maturin (Origin:— Barcelona)		SSC		Creole
Monagas	Socony-Vacuum	No. 1 Soledad	N 138,346.72—E 232, 901.93 (Origin:—Plaza Bolivar, Maturin)		SSC		So. Vac.

DISCUSSION AND COMMUNICATIONS

[In response to a request by the Editor, Mr. M. B. Dobrin, who acted as instructor in an ESMWT course in petroleum geophysics which was presented in Washington this Spring and Summer, has prepared the following account of the course for the assistance of those who may be interested in organizing similar courses in the geophysical centers.]

DESCRIPTION OF ESMWT COURSE IN PETROLEUM GEOPHYSICS CONDUCTED IN WASHINGTON, D.C.

Although 700 miles away from the nearest area where geophysical field parties ordinarily prospect for oil, thirty professional men and women in the vicinity of Washington, D. C., have evinced a sufficiently strong interest in petroleum geophysics to register for a fifteen week course in this subject when it was offered during the past spring and summer by George Washington University. The course was a part of the Engineering, Science, and Management War Training Program sponsored by the U. S. Office of Education to provide specialized training for work in essential war activities where there is a critical shortage of technically trained personnel. The government finances all instruction offered under this program, but leaves its administration to established institutions of collegiate standing. The program is in operation at several colleges and universities located near centers of geophysical activity and similar courses could probably be established at such places if there is sufficient demand. A brief description of the course taught at Washington might be useful to anyone interested in starting a class of the same kind elsewhere.

Despite an acute shortage of trained technical men for petroleum prospecting, admittedly essential war work, no geophysics courses had been offered under the auspices of the ESMWT program during the first three years of its existence. In January, 1944, the writer, believing that there was considerable potential interest around Washington in a Petroleum Geophysics course, approached Prof. Frank A. Hitchcock, in charge of the war training program at George Washington University, offering to teach such a course if the University would undertake its sponsorship. Prof. Hitchcock agreed to apply to the U. S. Office of Education for its approval. This was granted after a preliminary canvass, which Mr. J. F. Gallie made at the Interior Department, showed that seventeen persons there would be interested in enrolling. Classes were scheduled in two hour sessions two evenings a week for fifteen weeks beginning May 1.

Of the thirty people that enrolled, eleven were employed by the Petroleum Administration for War, three by the Geophysical Instrument Company, three by the Naval Ordnance Laboratory, two by the U. S. Geological Survey, and the remainder by various regular and wartime government agencies. Most of the PAW representatives were geologists, economic analysts, or refinery technologists. Four members of the class were in the Army, three of these being officers on detail to the Refining Division of the PAW. Three were women, two of them geologists, the third an attorney who dealt with oil lands and leases for the Interior Department. Almost all of those in the class had college degrees, three holding doctorates. Only two had been engaged directly in petroleum prospecting by geophysical methods, but one had had twelve years' experience on five continents.

For a group so heterogeneous in background and interests, it was difficult to decide

on a curriculum. The vast majority of the enrollees were too well established in other professions to look upon the course as vocational training for employment in geophysical work. These were more interested in learning the fundamental principles and applications of the various geophysical methods from the viewpoint of the oil company executive, geologist or technical expert in auxiliary or related fields. The textbook chosen for the course, "Geophysical Prospecting for Oil" by L. L. Nettleton, was especially applicable for a class of this composition.

The subject matter covered during each of the fifteen weeks was as follows:

1. Introductory material; fundamentals of petroleum geology
2. General survey of geophysical methods
3. Gravitational methods—fundamental principles
4–5. Gravity reductions and interpretation
6. Gravity instruments and field operations
7. Magnetic methods—fundamental principles
8. Magnetic interpretation
9. Magnetic instruments and field operations
10. Seismic prospecting—fundamental principles
11. Refraction methods—theory and interpretation
12. Reflection methods—theory and interpretation
13. Reduction of sample reflection records (problem)
14. Seismic instruments and field operations
15. Electrical prospecting and well logging; geochemical methods.

Class work consisted of lectures, discussions, and the working of problems requiring the reduction, plotting, contouring, and interpretation of geophysical field data. The problems were kindly furnished by Dr. Nettleton, who had devised them for courses he had taught in the subject at the University of Pittsburgh. The Gulf Research and Development Co. furnished prints of six seismograph records representing a mile of reflection shooting. These were worked up as a project for the class. Often various members of the class would bring in such valuable demonstration material as actual seismic reflection maps, electrical well logs, and even geophysical instruments.

Prof. Hitchcock obtained authorization for the instructor to invite a limited number of guest lecturers to address the class. Under this arrangement, the following speakers were heard, all being well known for their attainments in various geophysical fields:

1. Malvin G. Hoffman, Chief, Reserve Division, PAW: "Isostasy and its Relation to Gravity"
2. George B. Somers, Senior Physicist, Bureau of Ordnance, Navy Department: "Gravity Field Operations"
3. L. L. Nettleton, Staff Geophysicist, Gulf Research and Development Co.: "Gravity Effects around Salt Domes"
4. A. G. McNish, Magnetician, Department of Terrestrial Magnetism, Carnegie Institution of Washington: "The Earth's Magnetic Field"
5. L. C. Paslay, Partner, National Geophysical Co., and Physicist, Naval Ordnance Laboratory, "Seismic Instrumentation"

Although several members of the class remarked on occasion about the usefulness of the course in connection with their work, it must be acknowledged that its value in helping relieve the shortage of trained technical manpower in petroleum prospecting was

limited by two factors. One is the geographical separation of Washington from the areas of geophysical activity; the other is the fact that all those who enrolled in the course were already engaged in essential war work. However, as pointed out earlier, the same machinery is available for establishing similar courses of instruction in cities where they might be put to more immediate use. If the course given in Washington can set an example leading to further activity in the same direction it will have served its major purpose.

MILTON B. DOBRIN
Instructor

Naval Ordnance Laboratory
Washington, D. C.
August 27, 1944

PATENTS*

ELECTRICAL PROSPECTING

U.S. No. 2,343,140. H. M. Evjen. Iss. 2/29/44. App. 1/8/42. Assign. Nordel Corp.

Apparatus for Making Geophysical Explorations. An apparatus using commutated d-c for making four electrode earth resistivity measurements and made direct reading by passing a part of the ground current through a separate commutator and transformer whose secondary is synchronously rectified to produce d-c for feeding the potentiometer against which the earth potential is balanced.

U.S. No. 2,344,672. H. Blasier. Iss. 3/21/44. App. 3/23/40.

Method of Measuring Earth Potentials. A method of measuring potential differences between buried conductors and the ground or between ground points by using an electrode insulated from the ground and measuring the charging current of the condenser so formed.

U.S. No. 2,345,608. F. W. Lee. Iss. 4/4/44. App. 5/7/40.

Geophysical Prospecting. A method of making four electrode resistivity or impedisivity measurements to determine dip and strike by comparing potentials transverse to and in line with the current electrodes, and rotating the entire configuration until an azimuth of symmetry is found.

GEOCHEMICAL PROSPECTING

U.S. No. 2,345,219. R. F. Sanderson. Iss. 3/28/44. App. 12/30/39. Assign. Stanolind Oil and Gas Co.

Geochemical Prospecting. A method of collecting soil gas samples in which a container with hydrocarbon sorbent material is suspended in a shallow hole, allowed to remain a definite length of time, then closed and removed, the container having material to remove acid, alkali and water from the soil gas before adsorption of hydrobarcons.

U.S. No. 2,346,735. P. F. Daugherty and P. D. Barton. Iss. 4/18/44. App. 8/22/41. Assign. Sun Oil Company.

Method of Detecting Petroleum Deposits. A method of soil analysis prospecting in

* Abstracts by O. F. Ritzmann, Gulf Research & Development Company.

which soil samples or drill cores are heated to determine the amounts of water and of low boiling hydrocarbons and the ratio used as an index to locate petroleum.

U.S. No. 2,348,103. A. O. Beckman. Iss. 5/2/44. App. 1/31/40. Assign. American Geochemical Corp.

Method of Soil Analysis for Location of Oil Deposits. A method of soil analysis prospecting in which samples from shallow holes are analyzed for sulphide content.

U.S. No. 2,349,250. R. L. Doan. Iss. 5/23/44. App. 10/9/39. Assign. Phillips Petroleum Co.

Gas Detection. A method of analyzing soil gas for various hydrocarbons by placing it in a closed container having a platinum filament whose temperature change is observed in a bridge circuit and tested at successively higher filament temperatures.

U.S. No. 2,349,472. M. S. Taggart, Jr. Iss. 5/23/44. App. 6/7/39. Assign. Standard Oil Development Co.

Oil Prospecting Method. A method of soil analysis in which samples are placed in a sealed container with hydrocarbon gas and the rate of consumption of the gas observed to determine the amount of hydrocarbon consuming bacteria present.

GRAVIMETRIC PROSPECTING

U.S. No. 2,346,593. A. R. Lindblad and J. D. Malmqvist. Iss. 4/11/44. App. 1/5/40 and 1/2/41.

Damping Device in Gravimeters. A gravimeter having two suspended condenser plated and filled with a liquid to provide damping which is symmetrical about the null position.

U.S. No. 2,349,404. D. W. Blair and F. G. Boucher. Iss. 5/23/44. App. 7/22/41. Assign. Standard Oil Development Co.

Clamping Means for Force-Responsive Elements. A non-sticking suspended system clamp which has auxiliary fine wire springs to free the system from the main clamp, the wires being removed from contact by further motion of the clamp screw.

SEISMOGRAPH PROSPECTING

U.S. No. 2,345,288. W. E. Pugh. Iss. 3/28/44. App. 9/22/42. Assign. Seismograph Service Corp.

Method of Seismic Prospecting. A method of obtaining continuous subsurface seismograph control by shooting short and long shots into the same detector set-up from both ends.

U.S. No. 2,346,369. J. D. Eisler. Iss. 4/11/44. App. 2/28/42. Assign. Stanolind Oil and Gas Co.

Seismic Surveying. A distortionless seismograph amplifier with a band pass filter having a linear phase shift curve and whose cut-off frequencies are designed so that an extrapolation of the phase shift curve to zero frequency will give an apparent phase shift which is an integral multiple of π radians.

U.S. No. 2,348,225. O. S. Petty. Iss. 5/9/44. App. 2/13/40.

Magnetic Seismometer. A variable air gap reluctance type seismometer whose suspended system consists of an annular magnet and internal coil, the magnetic return circuit and air gap being inside the magnet.

U.S. No. 2,348,245. P. H. Dijksterhuis. Iss. 5/9/44. App. 4/9/41. Vested in Alien Property Custodian.

Device for Converting Variations of a Mechanical Quantity into Variations of an Electric Voltage. A modulated carrier system of measuring displacement in which the demodulated output controls the grid bias of an amplifier tube, so as to compensate for non-linearity in the transducer itself.

U.S. No. 2,348,401. L. Manzanera. Iss. 5/9/44. App. 7/28/42. Assign. Olive S. Petty.

Apparatus for Recording Wave Form Signals. A toothed wheel for putting timing lines on seismograph records and so designed to mark small intervals only on the edges of the record and large intervals all the way across.

U.S. No. 2,348,409. J. O. Parr, Jr. Iss. 5/9/44. App. 6/14/41. Assign. Olive S. Petty.

Seismic Surveying. A method of seismograph recording in which mixing is automatically varied with time by means of a motor driven cam, first arrivals being recorded unmixed and the degree and extent of mixing subsequently increased.

U.S. No. 2,348,411. O. S. Petty. Iss. 5/9/44. App. 2/8/41.

Method for Correlating Seismographic Curves. A method of redrawing seismograph records taken at different or variable tape speeds by tracing the record onto a transparent template also having timing marks and sliding it into proper position as the tracing progresses.

U.S. No. 2,349,186. E. Merten. Iss. 5/16/44. App. 8/31/42. Assign. Shell Development Co.

Sensitivity Control for Seismic Recording. A seismograph expander in which resistors shunting the detectors are initially immersed in mercury, the removal of the mercury being initiated by the first arrival and its rate controlled by the recorded signals.

U.S. No. 2,350,803. R. D. Newcomb. Iss. 6/6/44. App. 6/18/41.

Automatic Volume Control. An avc circuit for audio amplifiers in which a portion of the output is rectified and applied to the grids of two tubes whose plate circuits control the impedance of a center tapped shunting transformer.

U.S. No. 2,351,456. N. H. Ricker. Iss. 6/13/44. App. 8/29/41. Assign. Standard Oil Development Co.

Seismic Prospecting. A method of seismic recording in which the amplifier has a frequency characteristic which is the reciprocal of the ground attenuation-frequency characteristic and also a linear phase shift.

U.S. No. 2,351,524. R. L. Lay, B. H. Treybig, Jr. and L. M. Hubby. Iss. 6/13/44. App. 5/23/42. Assign. Texaco Development Corp.

Method of Seismic Prospecting. A method of avoiding secondary waves in water shooting by suspending the charge from a float at such depth to allow the water to blow out above the charge.

WELL LOGGING AND SURVEYING

U.S. No. 2,342,827. A. L. Ackers. Iss. 2/29/44. App. 5/28/40. Assign. Stanolind Oil & Gas Co.

Apparatus for Well Logging. A device for locating fluid interfaces in a well consisting of an electric heating coil with an adjacent thermostat which is lowered through the fluid and recording the operation of the thermostat so as to log the power required to maintain constant temperature.

U.S. No. 2,344,598. W. L. Church. Iss. 3/21/44. App. 1/6/42.

Wall Scraper and Well Logging Tool. A fluid pressure operated device for the end of the drill stem which scrapes the sides of the hole and collects a sample in a removable barrel and also equipped with a-c electrical logging electrodes.

U.S. No. 2,345,119. G. D. C. Hare. Iss. 3/28/44. App. 6/26/40. Assign. Texaco Development Corp.

Subsurface Prospecting. A method of well logging through the casing by lowering a source of gamma rays and a source of neutrons and simultaneously detecting with appropriate ionization chambers the scattered gamma radiation and scattered neutrons.

U.S. No. 2,345,770. S. Park. Iss. 4/4/44. App. 10/5/40. Assign. Eastman Oil Well Survey Corp.

Means for Surveying Well Bores. A well surveying instrument which is dropped through the drill stem just before the drill pipe is pulled and which records photographically at intervals during removal of the pipe, a record of the azimuthal orientation of the drill pipe being kept at the surface.

U.S. No. 2,345,829. W. J. Opocensky. Iss. 4/4/44. App. 1/20/40. Assign. Eastman Oil Well Survey Corp.

Means for Marking Record Elements. A device for marking accurately concentric reading lines on well surveying instrument disks and having a marking block which cuts lines into the disk when the block is rotated.

U.S. No. 2,345,864. J. C. Arnold. Iss. 4/4/44. App. 6/6/42. Assign. Lane-Wells Co.

Conductor Core for Wire Ropes and Method of Manufacture. A well logging cable consisting of a rubber insulated conductor reinforced with spiral cords which are covered with synthetic rubber and wound in opposite directions.

U.S. No. 2,346,203. W. M. Zaikowsky. Iss. 4/11/44. App. 12/7/40. Assign. Consolidated Engineering Corp.

Well Logging Method. A method of mud logging in which circulation is stopped for a short time to permit formation fluids to enter the mud and when circulation is resumed, analyzing samples taken from the mud corresponding to various well depths.

U.S. No. 2,346,481. A. D. Garrison. Iss. 4/11/44. App. 11/27/40. Assign. Texaco Development Corp.

Determination of Underground Strata. A method of fluorescence logging of uncased hole by transmitting ultra-violet light from a lamp to the wall through a quartz rod, and with another quartz rod transmitting the fluorescence to a filter and to a moving photographic film.

U.S. No. 2,346,789. E. E. Roper. Iss. 4/18/44. App. 6/15/42. Assign. Stanolind Oil and Gas Co.

Well Logging. A method of eliminating the effect of potassium on radioactivity logs by taking samples of the formations, spectrographically determining their potassium content and its effect on the instrument and subtracting this from the log.

U.S. No. 2,347,794. R. G. Piety. Iss. 5/2/44. App. 3/15/41. Assign. Phillips Petroleum Co.

Well Surveying Device. A method of electrical well logging using a surface electrode and a long cylindrical electrode having in the middle an insulated section whose current or potential may be measured separately as the assembly is moved in the hole.

U.S. No. 2,349,225. S. A. Scherbatskoy, G. Swift, R. E. Fearon and J. Neufeld. Iss. 5/16/44. App. 9/15/41. Assign. Well Surveys, Inc.

Well Logging Instrument. A gamma ray well logging apparatus having an ionization chamber and two resistors in series, one of which is fed by current supplied and recorded at the surface, the condition of balance of the two resistor potentials being automatically signaled to the surface and automatically adjusted.

U.S. No. 2,349,366. C. A. Moon. Iss. 5/23/44. App. 3/12/42. Assign. Socony-Vacuum Oil Co., Inc.

Method of Geophysical Prospecting. A method of well logging in which a radioactivity logging instruent is dropped into the drill stem when it is raised off bottom to add a new length of pipe, the log being taken while the pipe is lowered to bottom, and the instrument then fished out on a wire line.

U.S. No. 2,349,712. R. E. Fearon. Iss. 5/23/44. App. 11/10/38 and 1/28/43. Assign. Well Surveys, Inc.

Well Logging Method and Device. A well logging device having a neutron emitting source and a properly shielded ionization chamber to detect scattered gamma radiation produced in the formations by the neutrons.

U.S. No. 2,349,753. B. Pontecorvo. Iss. 5/23/44. App. 2/5/42. Assign. Well Surveys, Inc.

Method and Apparatus for Geophysical Exploration. A method of gamma ray well logging in which the hardness of radiation is determined by using a divided Geiger counter and measuring the ionization in each side and also the coincidences.

U.S. No. 2,350,371. G. A. Smith. Iss. 6/6/44. App. 7/23/40. Assign. Sperry-Sun Well Surveying Co.

Borehole Logging Apparatus. An acoustic logging device having a sound transmitter and receiver with electrical feedback to cause oscillation whose frequency depends on the rock velocity.

U.S. No. 2,350,832. F. F. Segesman. Iss. 6/6/44. App. 2/21/41. Assign. Schlumberger Well Surveying Corp.

Electrical Depth Marker. An electrically detectable marker for wells consisting of a

ring of an electrically dissimilar metal or an insulating ring on the inside surface of the casing, or in open hole a gun perforator bullet made of two metals constituting an electrolytic couple.

U.S. No. 2,351,028. R. E. Fearon. Iss. 6/13/44. App. 9/17/41. Assign. Well Surveys, Inc.

Well Surveying Method and Apparatus. A method of gamma ray well logging in which the ion pulse produced in the ionization chamber is proportional to the gamma ray energy and having a recording circuit which will record each separate pulse so that a gamma ray frequency spectrum may be obtained.

MISCELLANEOUS

U.S. No. 2,342,685. A. S. Norcross. Iss. 2/29/44. App. 5/8/41.

Measuring System. A follow-up device for continuously measuring and indicating a condition manifested as a high electrical resistance and using a thermionic tube to maintain constant current through a resistance in series with the one to be measured.

U.S. No. 2,343,063. E. L. Kent. Iss. 2/29/44. App. 10/31/42. Assign. C. G. Conn, Ltd.

Method of and Apparatus for Measuring Mechanical Vibrations. A mechanical vibrometer having a mass on an arm which is supported by damped springs whose angle with the arm may be changed to vary the natural frequency of the system.

U.S. No. 2,344,296. F. W. Frink. Iss. 3/14/44. App. 1/25/38 and 11/29/40.

Means and Method for Cathode Ray Oscilloscope Observation and Recordation. A method of observing several cathode ray tube screens simultaneously by looking at one with one eye and at a second with the other eye or by optically superimposing images of the screens through the use of partially reflecting mirrors, or by observing the screens in rapid succession by using a rotating mirror.

U.S. No. 2,344,344. C. Dorsman, M. F. Reynst and R. Veldhuizen. Iss. 3/14/44. App. 2/26/41. Vested in Alien Property Custodian.

Device for Oscillographing Electrical or Mechanical Processes. A device for balancing a remotely located a-c bridge circuit whose unbalance is observed with a cathode ray oscilloscope, by introducing into the observed bridge voltage a component derived from the a-c exciter and adjusting its phase and amplitude.

U.S. No. 2,344,642. A. C. Ruge. Iss. 3/21/44. App. 9/16/39 and 8/5/42.

Temperature Compensated Strain Gauge. A filament type electric strain gauge having a strain-free temperature compensating element suspended as a cantilever slightly above the strain element and the two elements connected in adjacent arms of a Wheatstone bridge circuit.

U.S. No. 2,344,647. E. E. Simmons, Jr. Iss. 3/21/44. App. 2/23/40 and 1/1/42.

Method and Apparatus for Making Strain Gauges. A production jig for winding filament type electric strain gauges which insures tautness of the wires and uniformity in characteristics.

U.S. No. 2,344,648. E. E. Simmons, Jr. Iss. 3/21/44. App. 6/20/42.

Moisture Proof Strain Gauge. A filament type electric strain gauge which is bonded to the inside of a sealed tube also containing a strain free dummy for temperature compensation, the tube being arranged to engage the test body.

U.S. No. 2,345,654. C. H. Bowman. Iss. 4/4/44. App. 6/6/38. Assign. Trojan Powder Co.

Explosive Cartridge. A waterproof explosive wrapper having longitudinal scores on the cylindrical surface so that when end pressure is applied in tamping the explosive expands in diameter to completely fill the hole.

U.S. No. 2,345,887. J. E. Rothrock. Iss. 4/4/44. App. 4/5/40. Assign. Hercules Powder Co.

Method of Sealing Containers. A method of sealing plastic explosive containers by having an internal recess filled with mastic material into which a pre-cooled internal plug is thermally expanded.

U.S. No. 2,345,935. G. L. Hassler. Iss. 4/4/44. App. 4/6/42. Assign. Shell Development Co.

Method and Apparatus for Permeability Measurements. A method of measuring permeability of rock samples under polyphase fluid flow by forcing fluid around a closed system and measuring the pressure drop across the sample in a separate closed system.

U.S. No. 2,346,043. K. J. Mysels. Iss. 4/4/44. App. 3/2/42. Assign. Shell Development Co.

Pipe-Line Leak Detecting Method. A method of detecting leaks in pipe lines by dissolving a small amount of radioactive substance in the material carried by the pipe and subsequently measuring the radioactive intensity along the pipe line.

U.S. No. 2,346,093. W. A. Tolson. Iss. 4/4/44. App. 10/22/41. Assign. Radio Corp. of America.

Sonic Depth Indicator. A sonic depth indicator having a slowly charging condenser discharged by the initial pulse and again discharged by the amplified reflected pulse, the depth being indicated by the current on discharge by the amplified reflected pulse.

U.S. No. 2,346,486. D. G. C. Hare. Iss. 4/11/44. App. 10/7/41. Assign. The Texas Company.

Method and Apparatus for Measuring Thickness. A method of measuring thickness of a plate by placing a source of penetrating radiation on one side and observing the transmitted radiation at three random points on the other side and geometrically determining the transmitted intensity which would be observed at a point directly opposite the source.

U.S. No. 2,346,655. H. Benioff. Iss. 4/18/44. App. 4/18/41. Assign. Submarine Signal Company.

Electrodynamic Vibrator. A supersonic submarine signalling vibrator having a number of electro-dynamic driving elements in each of which the moving coil is connected to the diaphragm through a half-wave length resonant vibrating system.

U.S. No. 2,347,702. H. B. Maris. Iss. 5/2/44. App. 4/11/41.

Device for Measuring Extremely Small Angles. An optical device for measuring small angular motion between plane mirrors by measuring the displacement of a high order multiple reflection image.

U.S. No. 2,347,759. T. C. Wherry. Iss. 5/2/44. App. 3/29/41. Assign. Phillips Petroleum Co.

Fishing Tool. A fishing tool which is supported on an electric conductor cable, the tool being equipped to indicate at the surface the proximity or contact with the fish either magnetically, electrically or by radioactivity.

U.S. No. 2,348,520. W. T. Cardwell, Jr. Iss. 5/9/44. App. 5/5/42. Assign. Standard Oil Co. of California.

Suspendometer. A device for comparing the relative capacities of fluids to support suspended material and consisting of an immersed frame with a shelf holding balls of graduated diameters, the frame being moved aside for a definite time and then returned to catch the balls on lower shelves.

U.S. No. 2,348,810. D. G. C. Hare. Iss. 5/16/44. App. 5/29/40. Assign. The Texas Co.

Method and Apparatus for Determining Liquid Level. A method of locating the liquid level through a closed container by moving vertically on the outside a source of gamma rays together with a detector of scattered radiation.

U.S. No. 2,348,985. J. A. Lewis. Iss. 5/16/44. App. 4/19/40. Assign. Core Laboratories, Inc.

Method for Determining Permeability. Measuring the permeability of rock samples by forcing air into a small circular area on a large face of the sample and observing the pressure and rate of flow obtained.

U.S. No. 2,349,429. G. Herzog and J. H. Stein. Iss. 5/23/44. App. 4/29/42.

Method and Apparatus for Measuring Thickness. A method of measuring thickness of pipe by passing penetrating radiation through the wall in a tangential direction and measuring the absorption.

U.S. No. 2,350,072. E. E. Simmons, Jr. Iss. 5/30/44. App. 2/23/40 and 1/1/42.

Torque Measuring Apparatus. A torsion dynamometer in which the torque transmitting member has tangential arms carrying bonded filament type electric strain gauges.

U.S. No. 2,350,073. E. E. Simmons, Jr. Iss. 5/30/44. App. 5/8/42.

Strain Gauge and Method for Making Same. A filament type electric strain gauge in which an insulated wire filament is embedded in a thermoplastic material which may be bonded to the test member by application of heat.

U.S. No. 2,350,566. G. R. Mustaparta. Iss. 6/6/44. App. 3/25/41. Assign. Hercules Powder Co.

Primer Tube for Dynamite Cartridges. A tube having a narrow inside pocket into

which a blasting cap may be placed so that the cap is not disturbed when the dynamite is inserted to make up the primer.

U.S. No. 2,350,712. W. Barsties. Iss. 6/6/44. App. 3/25/41. Vested in Alien Property Custodian.

Fluid Level Gauge. An immersion type tank fluid level gauge consisting of a long right angle prism having an extended light source along one base and an extended photocell along the other base, the light being totally reflected at the hypotenuse to the photocell only where not immersed in liquid.

U.S. No. 2,350,972. A. C. Ruge. Iss. 6/6/44. App. 9/16/39.

Strain Gauge. A wire filament type strain gauge having two wires of different and opposite thermal coefficients of resistance so that temperature compensation may be obtained.

U.S. No. 2,351,003. M. Camras and W. Korzon. Iss. 6/13/44. App. 9/11/40. Assign. Armour Research Foundation.

Recording and Reproducing of Vibrations. A recording and play-back head for longitudinal magnetic recording on a steel wire which enters and leaves the recording gap through the pole pieces.

U.S. No. 2,351,004 to 2,351,011. M. Carmas. Iss. 6/13/44. App. 12/22/41 to 2/25/43. Assign. Armour Research Foundation.

Method and Means of Magnetic Recording. A method of magnetic recording on a steel wire, elimination of disturbances, recording head designs, and control devices for magnetic recorders.

U.S. No. 2,351,201. R. Gillis. Iss. 6/13/44. App. 7/16/42. Assign. Western Electric Co.

Method and Means for Measuring. A direct reading a-c four electrode method of measuring the thickness of a metallic sheet by passing a current between two points far apart and measuring the potential between two intermediate points close together.

U.S. No. 2,351,353. M. D. McCarty. Iss. 6/13/44. App. 12/19/41. Assign. Socony-Vacuum Oil Co., Inc.

Galvanometer. A galvanometer element having a double coil, one of which is used for recording the signal and the other either for exciting an avc circuit, mixing, inverse feedback or damping.

U.S. No. 2,351,457. W. M. Rust, Jr. and M. A. Arthur. Iss. 6/13/44. App. 11/25/40. Assign. Standard Oil Development Co.

Grating Spectrograph. A spectrograph control unit which opens a shutter a predetermined time after the light source is started, closes the shutter a predetermined interval later and gives an audible signal which may be used to gauge photographic developing time.

U.S. No. 2,351,508. H. G. Hamilton. Iss. 6/13/44. App. 5/8/43. Assign. The Singer Manufacturing Co.

Electric Motor Control System. A speed control for small series motors consisting of

tandem rheostats, one of which is in series with the motor and the other of which controls the rectified current energizing a magnetic brake so that the brake is released as the motor is speeded up.

Erratum

In the July 1944 number, under Geochemical Prospecting, patent U.S. No. 2,239,651 should read U.S. No. 2,339,651.

PUBLICATIONS RECEIVED

(The publications listed below were received since issuance of GEOPHYSICS for July, 1944, and are available for loan to the membership. Articles cited are those of particular interest to geophysicists.)

American Journal of Science, Vol. 242, No. 6 ("Thorium-Uranium Ratios in Rocks and Minerals," by N. B. Keevil, and "Radioactive Substances, III, The Analysis and Age of a North Carolina Monazite," by Allen Douglass Bliss), and 7 ("The Distribution of Helium and Radioactivity in Rocks, VI, The Ayer Granite-Migmatite at Chelmsford, Mass.," by N. B. Keevil, E. S. Larsen and F. J. Wank), and 8 (June, July, August, 1944), New Haven.

Basic Principles of Weather Forecasting, by Victor P. Starr, Harper and Brothers, Publishers, New York.

Bulletin of the Academy of Sciences of the Union of Soviet Socialist Republics. No. 4 (1943), and 6 ("The Study of Electric Current on Models," by J. P. Bulashevitsh), 1943, Moscow.

Bulletin of the American Association of Petroleum Geologists, Vol. 28, Nos. 7, 8 (July, August, 1944), Tulsa.

Economic Geology, Vol. XXXIX, No. 4 (June–July, 1944), Lancaster.

Independent Petroleum Association of America Monthly, The, Vol. XV, Nos. 2, 3 and 4 (June, July, August, 1944), Tulsa.

Journal of Applied Physics, Vol. 15, Nos. 5, 6, 7 and 8 (May, June, July, August, 1944), Lancaster.

Journal of the Institute of Petroleum, Vol. 30, Nos. 244, 245 (April, May, 1944), London.

Petroleum, Vol. VII, Nos. 5, 6 and 7 (May, June, July, 1944), London.

Review of Scientific Instruments, The, Vol. 15, Nos. 5, 6 (May, June, 1944), and 7 ("Magnetometer for the Determination of the Vertical Component of the Earth's Magnetic Field," by S. L. Ting and S. T. Lin), July, 1944, Lancaster.

Terrestrial Magnetism and Atmospheric Electricity, Vol. 49, No. 2 (June, 1944), Baltimore.

World Petroleum, Vol. 15, No. 6 ("Oil Search in the Eastern Gulf Region," by Joseph A. Kornfeld), 7 and 8 (June, July, August, 1944), New York.

CONTRIBUTORS

JOHN SLOAT

JOHN SLOAT received the B.S. and M.S. degrees in electrical communications from the Massachusetts Institute of Technology in 1934. During 1932–33 he was employed by the Bell Laboratories of New York City where he helped develop a system for the measurement of the absolute values of sound pressures. In 1934 he was employed by the Western Geophysical Company, where he held in succession positions as driller, observer, computer, and party chief. In 1937 he became associated with the Union Oil Company of California in his present position where he is concerned with problems of geophysical interpretation and supervision. Mr. Sloat is a member of the Society of Exploration Geophysicists.

MONROE W. KRIEGEL

MONROE W. KRIEGEL received his B.S. degree in 1934, M.S. in 1936, and Ph.D. degree in Chemical Engineering in 1939, all from the University of Texas. While doing graduate work at that school he was an instructor in chemistry for three years, and was a research associate in the Bureau of Industrial Chemistry for two years, working on problems associated with the decomposition of methane by high voltage discharge.

After leaving school, he worked as field testing engineer for the Oil and Gas division of the Texas Railroad Commission. For a year and a half he served as professor of chemical engineering at Texas College of Arts and Industries. In December, 1940, he joined The Carter Oil Company as a research geophysicist in geochemical work.

He is a member of the American Chemical Society, The American Institute of Mining and Metallurgical Engineers, Phi Lambda Upsilon, Tau Beta Pi, and associate of Sigma Xi. He holds a Texas professional engineer's license in chemical engineering.

E. G. KOGBETLIANTZ

ERVAND GEORGE KOGBETLIANTZ was born in southern Russia of Armenian parents. He graduated from the University of Moscow, and received the degree of Docteur es Sciences Mathematique at the Sorbonne in Paris. In 1927 he founded, with the financial participation of the Banque de Paris et de Pays Bas and the Compagnie Francaise des Petroles, the firm Société de Prospection Géophysique, which engaged in gravity and magnetic explorations. In 1933 Dr. Kogbetliantz was sent by the government of France on a scientific mission to Iran, where he was appointed by the Iranian government as Professor of Applied Geophysics at the University of Teheran, a post he filled for five years. In 1938 he returned to France as a staff member of the National Center of Scientific Research, assigned to study and improve the interpretation of geophysical maps. Dr. Kogbetliantz came to the United States in June of 1942 at the invitation of Lehigh University, where he has been teaching mathematics and continuing with his researches.

THOMAS S. WEST

THOMAS S. WEST attended the University of Oklahoma for four years during the period 1922–28, and returned in 1930 for additional work in physics. During 1928–29 he was employed as an engineer by the Tidal Refining Company. During the years 1931–41 he was associated with the McLaren, Grimes and Patterson interests of Dayton, Ohio, in electrical prospecting research and petroleum exploration and development. Mr. West has been in charge of geological and engineering work for the Henderson-Coquat interests of San Antonio, Texas, since 1941.

CLARENCE C. BEACHAM

CLARENCE C. BEACHAM received the degree of B.S. in mining engineering from Ohio State University in 1928. He was employed by the Gypsy Oil Company as an engineer in the Seminole area and as district engineer in the Drumright district during 1928–32. During 1931–41 he was associated with the McLaren, Grimes and Patterson interests of Dayton, Ohio, in electrical prospecting research and petroleum exploration and development. Mr. Beacham has been part owner and manager of the Harbough-Potts Coal Company of Somerset, Ohio, since 1942.

B. G. Swan's photograph and biography appeared in Vol. VII, No. 4, p. 425 (October, 1942).

THE SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the Secretary within thirty days. (Names of sponsors are placed beneath the name of each nominee.)

ACTIVE

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STUDENT

Paul Clarence Wuenschel
R. Maurice Tripp

PRELIMINARY ANNOUNCEMENT OF FIFTEENTH ANNUAL MEETING OF THE SOCIETY

The S.E.G. will meet concurrently with the A.A.P.G. and S.E.P.M. in Tulsa, March 20–22. Mr. Henry C. Cortes, Vice-President of the S.E.G., is General Chairman of the Program and Arrangements Committee. He will be assisted by a host city arrangements committee, a host city program committee, and program committee members from various regions of the country.

The chairman of the host city arrangements committee is T. A. Manhart, Seismograph Service Corporation, 712 Kennedy Building, Tulsa 3. The chairman of the host city program committee is L. Y. Faust, Geophysical Research Corporation, Box 2040, Tulsa 2. Other host city committee members and regional members of the program committee will be listed in the January number of GEOPHYSICS and in the complete announcement of the meeting to be circulated to all members.

Members of the Society should begin to think about the preparation of papers for presentation in person or by title at the annual meeting, and for subsequent publication in GEOPHYSICS. If there is a possibility that you may be able to prepare a paper, or if you know another member who is likely to be able to prepare a paper, kindly communicate this information to the General Chairman of the Program and Arrangements Committee.

PERSONAL ITEMS

BILLY E. RICHARDS, formerly with the United Geophysical Company, is now serving as a Lieutenant in the U. S. Army Air Forces. He may be addressed at A.P.O. 713, Unit 1, c/o Postmaster, San Francisco, Calif.

J. CARR is being transferred from the Shell Co. of Australia to the Shell Co. of Egypt Ltd., Cairo, Egypt.

ODELL C. OLSON is a Captain in the U. S. Marine Corps Reserves. His mailing address is P. O. Box 349, Brady, Texas.

CHARLES C. WILLIAMS, formerly with the National Geophysical Co., is now associated with the General Geophysical Co., 2513–14 Gulf Bldg., Houston 2, Tex.

JACK F. JUDSON, of the United Geophysical Co., has been trasnferred from San Felipe, Yaracuy, Venezuela, to Caracas. He may be addressed in care of the company at Aptdo. 1085.

H. G. DOLL is Chairman of the Board of Directors and Director of Research of the Schlumberger Well Surveying Corp., 2720 Leeland, Houston, Tex.

LT. IR. J. J. H. JANSEN M., who has been serving with the Dutch Air Forces, may now be reached through the Netherlands Military Mission, 2010 Massachusetts Ave., NW., Washington, D. C.

G. F. KAUFMANN, who has been serving overseas with the Standard-Vacuum Oil Co., is now located in New York for an indefinite period and may be addressed at Room 1421, 26 Broadway, in care of that company.

PAUL FARREN is now residing at 807 Sixth St., Ballinger, Tex.

WHEATON C. CLARK has left the Continental Oil Co. to accept a position as District Geologist with the British-American Oil Producing Co., 312 Con Roy Bldg., Casper, Wyo.

VINCENT J. MERCIER, of the Lane-Wells Co., has notified the Society of his transfer to Wichita 2, Kansas, from Pratt. The Lane-Wells office is at 806 Central Bldg.

RICHARD WILLIAMS, Supervisor with the National Geophysical Co., is located in Palestine, Texas, with the postal address P. O. Box 487.

A. A. HUNZICKER, of the Texas Co., has been transferred from Nashville, Ill., to Colby, Kansas.

LT. S. C. STONEHAM may be addressed at P. O. Box 375, Waxahachie, Tex.

S. H. WILLISTON, Vice President of Horse Heaven Mines, Inc., and the Cordero Mining Co., has moved from Portland, Oregon, to 703 Mechanics' Institute Bldg., 57 Post St., San Francisco 4, Calif.

H. C. BICKEL, Chief Geophysicist with the Tropical Oil Co., is located at Bogota, Colombia, with the following addresses: Aptdo. Aereo 3533 and Aptdo. Nacional 335.

R. MAURICE TRIPP has left the Colorado School of Mines to serve as Assistant to

the President of the Geotechnical Corp. His address is 149 Sidney St., Cambridge 39, Mass.

LEWIS H. BOYD, of the Brown Geophysical Co., has moved from Bakersfield, Calif., to Tallahassee, Fla., where his postal address is Box 724.

J. W. THOMAS, of Geophysical Service, Inc., is supervising work with the Department of Exploration, Petroleos Mexicanos, Av. Juarez 95, Mexico, D. F.

V. L. JONES is now Physicist with the Stanolind Oil and Gas Co., 1321 S. Carson, Tulsa, Okla.

LAWRENCE A. GOEBEL, of the Carter Oil Co., may be addressed at P. O. Box 801, Tulsa, Okla.

DAVID M. WEBER has returned from foreign duty with the Mene Grande Oil Co. and may be addressed in care of the Gulf Res. and Dev. Co., Box 352, Laurel, Miss.

GEORGE B. STONE, after serving in the Naval Ordnance Laboratory for the past year, has joined the Phillips Petroleum Co., 521 Esperson Bldg., Houston 2, Texas, as Geologist and Geophysicist. His residence address is 2234 Tangley Rd. in that city.

LEONARD J. NEUMAN has offices at 943 Mellie Esperson Bldg., Houston 2, Tex.

C. RUSSELL HALE, Party Chief with the United Geophysical Co., and recently transferred from Brazil to Venezuela, is having his mail forwarded to him from his home address, 502 Meander St., Abilene, Tex.

PAUL H. BOOTS, of the Gulf Res. and Dev. Co., is now serving with the Colombian Gulf Oil Co., Aptdo. Aereo 40-14 or Aptdo. Nacional 1339, Bogota, Colombia, S. A.

HARDEE CHAMBLISS, retired Professor of Chemistry, and sometimes Dean of the School of Engineering, Catholic University of America, has joined the staff of the Geophysical Instrument Co., Arlington, Va., as Consulting Chemist. In the Graduate School of the U. S. Dept. of Agriculture, Dr. Chambliss will give a general, introductory course in geochemistry. Geochemical prospecting for oil and minerals will be among the topics discussed. This is probably the first course of the kind to be offered in the U. S.

A. L. WILKINSON, of the Petty Geophysical Engineering Co., has been transferred from Homestead, Fla., to Sour Lake, Tex. His postal address is Box 415.

CAPTAIN LYNN A. SMITHERMAN, U. S. Army Signal Corps., should be addressed at P. O. Box 67, Athens, Tex.

LT. COL. DREXLER DANA should be addressed at Box 949, Route 7, Bakersfield, Calif.

The mailing address for F. W. OUDT and T. ROZSA, of the Shell Oil Co., Inc., has been changed from Box 1007 to Box 1049, Saginaw, Mich.

LT. D. G. EGAN, U. S. Army Signal Corps, may be addressed at P. O. Box 366, Crowley, La.

H. G. MACE, of the United Geophysical Co., recently elected to associate mem-

bership in the Society, is working in the mid-continent area. He may be addressed at 804 Thompson Bldg., Tulsa 3, Okla.

O. A. SEAGER has joined the staff of the Standard Oil Co. of Egypt, 22 Sharia Kasr el Nil, Cairo, Egypt.

JOHN A. LESTER, Seismic Supervisor with the Magnolia Petroleum Co., has been transferred from Dallas to Houston, Texas, with the postal address Box 111.

DON B. HEANEY, formerly Computer on Western Geophysical Co. Party 20, is now serving as Radio Technician Second Class in the U. S. Navy. He may be reached through the Fleet Post Office, San Francisco, Calif.

LELAND W. JONES, of the Anderson-Prichard Oil Corp., advises the Society of the change of offices from Oklahoma City to 609 Orpheum Bldg., Wichita 2, Kansas.

CAPTAIN MERLE C. BOWSKY, of the U. S. Army Signal Corps, may be addressed at A.P.O. 5541, c/o Postmaster, New York, N. Y.

WALTER D. BAIRD, Party Chief for Geophysical Service, Inc., has been transferred to the Mid-Continent area, and may be addressed at 1311 Republic Bank Bldg., Dallas, Texas.

JAMES A. LONG, Party Chief with the Stanolind Oil and Gas Co., should be addressed in care of the company at Box 591, Tulsa, Okla.

R. G. SOHLBERG is Geophysicist with South Mediterranean Oilfields, Ltd., 43 Sharia Kasr el-Nil, Cairo, Egypt.

ROBERT G. NISLE has been advanced to the rank of Lt. (j.g.), and is serving as Project Officer, Bureau of Ordnance, U. S. Navy Dept. His residence address in Washington, D. C., is 332 Raleigh St., SE.

J. B. SOUTHER, Consulting Geologist and Geophysicist, has returned to San Antonio, Texas, from Lincoln, Nebraska. He may again be addressed at 239 Luther Drive, San Antonio 1.

G. W. CARR announces the establishment of the Carr Geophysical Co., with offices at 1321 Commerce Bldg., Houston 2, Tex.

G. W. GULMON, Geologist with the California Co., may be reached in Ferriday, La., at Box 546.

LT. R. G. PATERSON, R. C. N. V. R., is Electrical Anti-Mining Officer with the Royal Canadian Navy. His mailing address is c/o Fleet Mail Office, Vancouver, B. C., Canada.

C. H. ACHESON has returned to Canada from South America. He is located at 301 Examiner Bldg., Calgary, Alberta, Canada.

ROY LEE GALLEWAY, of the Texas Co., has left Lafayette, La., for Plaquemine, where his postal address is Box 150.

The PETROLEUM ADMINISTRATION FOR WAR reported in September that there were 481 geophysical units operating in the United States, as follows: seismic, 290 units; gravimeter, 124 units; core drills, 47 units; magnetic, 17 units; torsion balance, 1 unit; electrical, 2 units. The number of units operating increased by 72 since January 1, 1944.

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THE SOCIETY OF EXPLORATION GEOPHYSICISTS

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W. HARLAN TAYLOR ..... *Secretary-Treasurer*
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JOSEPH A. SHARPE ..... *Editor*
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R. D. WYCKOFF ..... *Past President*
Gulf Research and Development Co., Pittsburgh, Pennsylvania

GEOPHYSICS is the official publication of the Society of Exploration Geophysicists and is published four times a year, January, April, July and October. $3.00 ($3.50 foreign) of the annual dues is set aside for payment of the annual subscription to the Society Journal, GEOPHYSICS. The subscription rate to non-members is $6.00 per year (plus 50 cents additional for postage to foreign addresses).

Requests for information on applications for membership, claims for non-receipt of numbers, subscriptions, and all other business matters should be sent to the Business Manager of the Society: J. F. Gallie, 450 Ahnaip Street, Menasha, Wisconsin, or P.O. Box 410, El Dorado, Arkansas. **Claims for non-receipt of preceding numbers of GEOPHYSICS must be sent to the Business Manager within three months of the date of publication in order to be filled gratis.**

Editorial matters should be sent to the Editor of the Society: Joseph A. Sharpe, P.O. Box 591, Tulsa 2, Oklahoma.

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The Society of Exploration Geophysicists

Society: The Society of Petroleum Geophysicists was organized in 1930 at Houston, Texas. In 1936, the Society approved a change in name to the Society of Exploration Geophysicists, to indicate the close association of the aims and objects of the Society with the newly recognized primary function of Exploration, which has recently been recognized by the petroleum industry as being on a par with Production, Transportation, Refining, and Marketing.

Aims and Objects: The Society functions for the promotion of the science of geophysics, especially as it relates to petroleum geology and to the discovery and production of oil and natural gas and associated minerals, and the maintenance of a high professional standard among its members. Among the methods of accomplishing these objectives is the publication of papers, discussions, and communications of interest to the membership.

Journal: GEOPHYSICS is the official publication of the Society, and in it are published all of the papers, discussions, and communications received from the membership which are accepted for publication by the Editor. Copies are sent to all members of the Society in good standing. $3.00 ($3.50 foreign) of the annual dues is set aside for payment of the annual subscription to the Society Journal, GEOPHYSICS. The subscription price to non-members is $6.00 per year, with an additional charge for postage where such is necessary. Claims for non-receipt of preceding numbers of GEOPHYSICS must be sent to the Business Manager within three months of the date of publication in order to be filled gratis.

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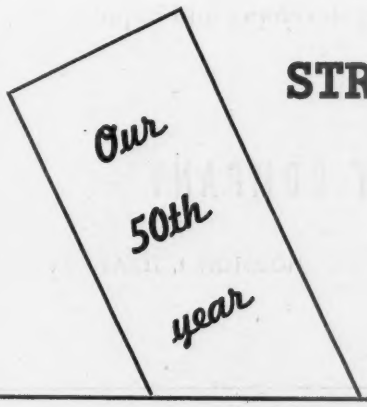

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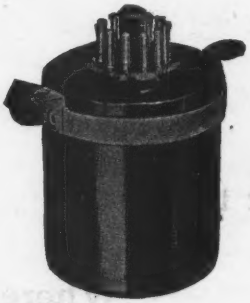

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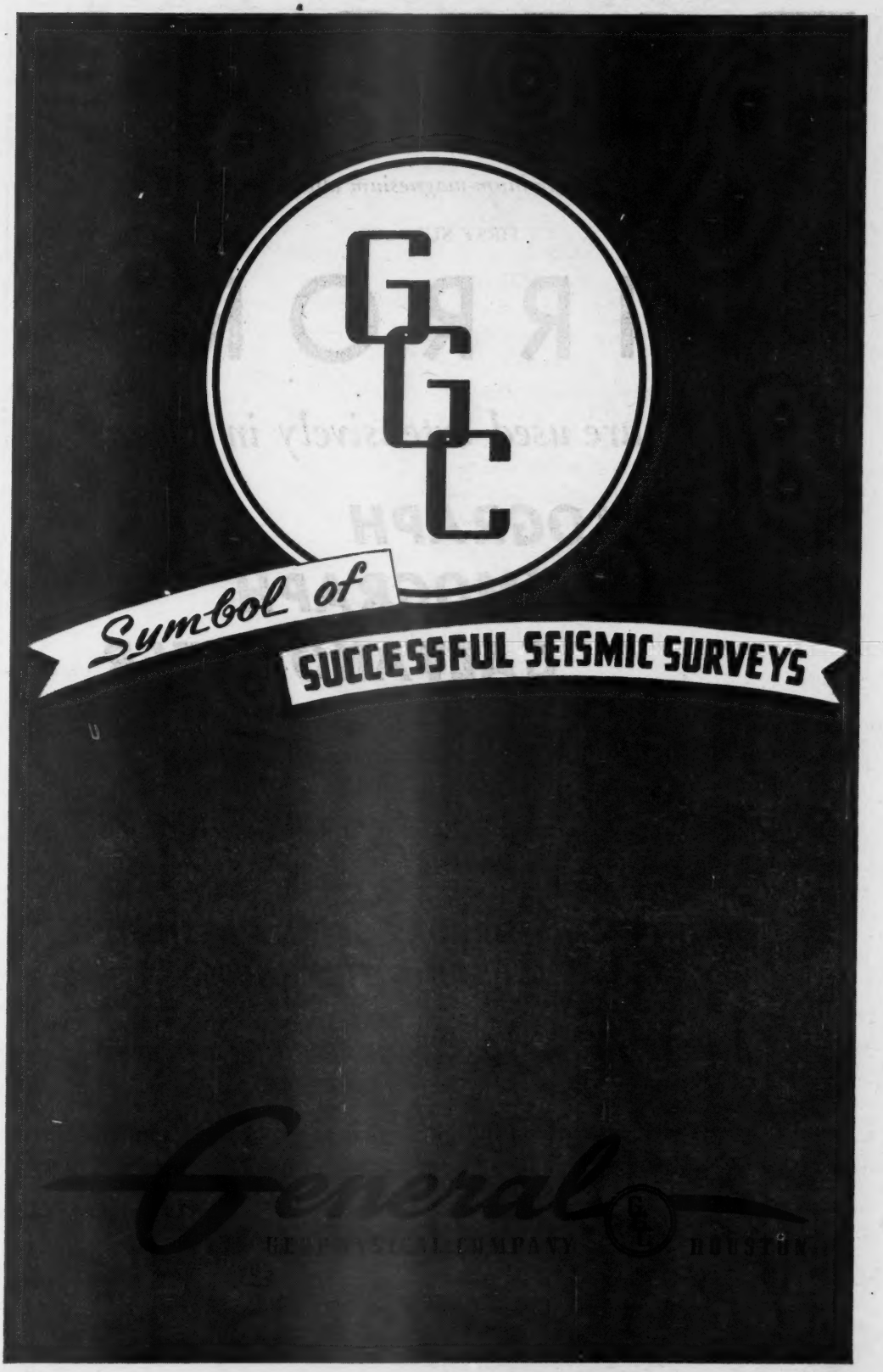
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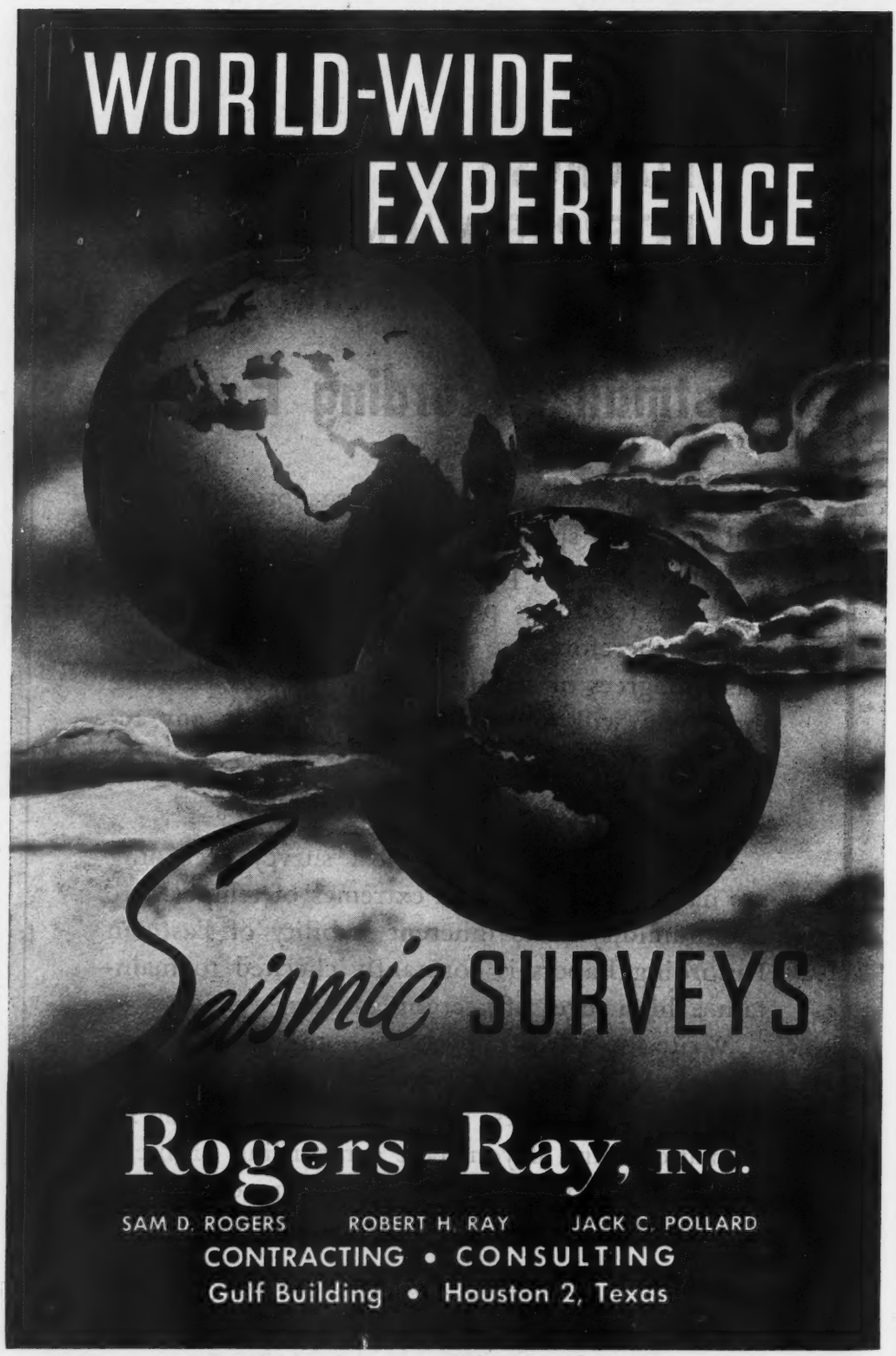
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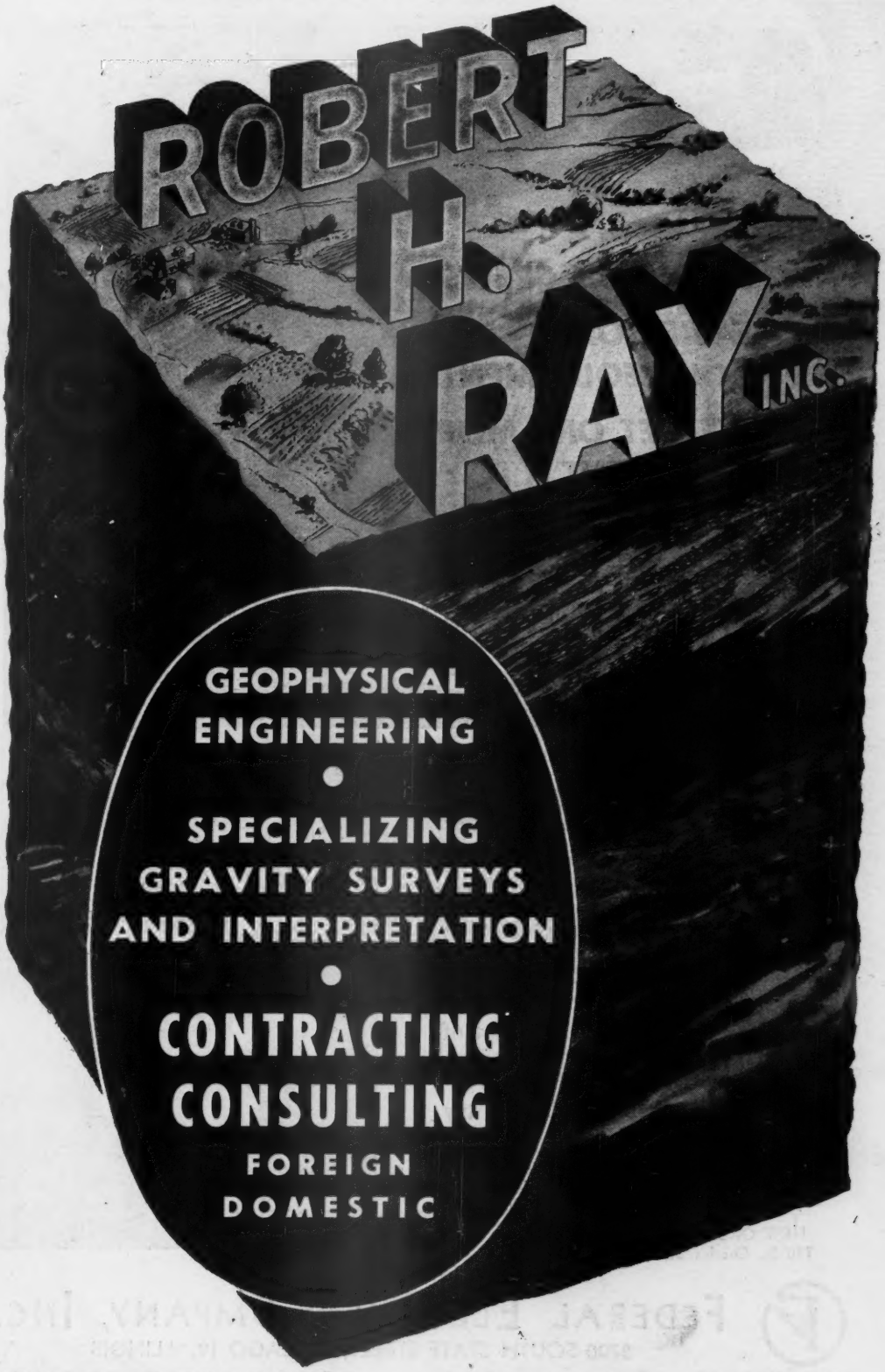

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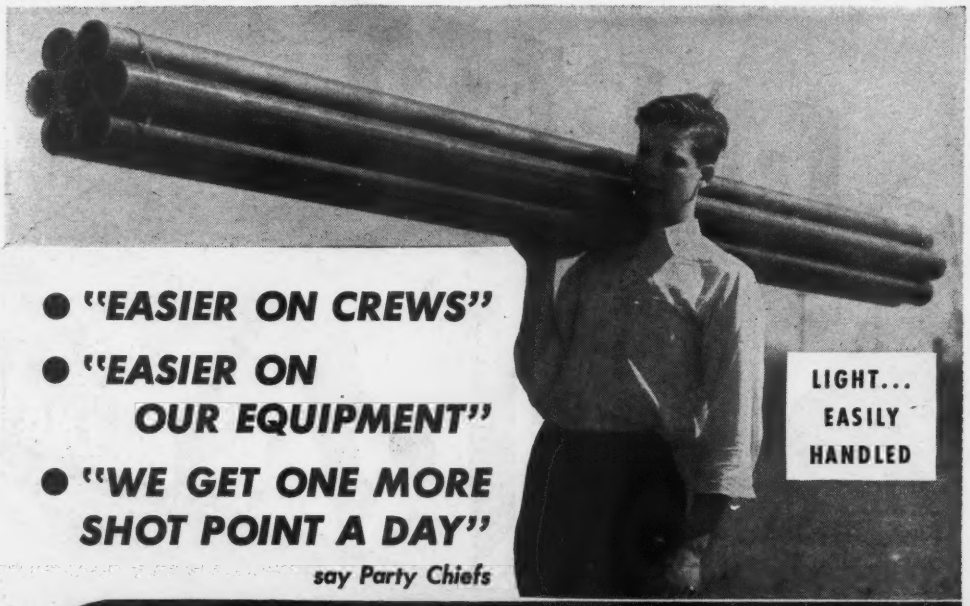

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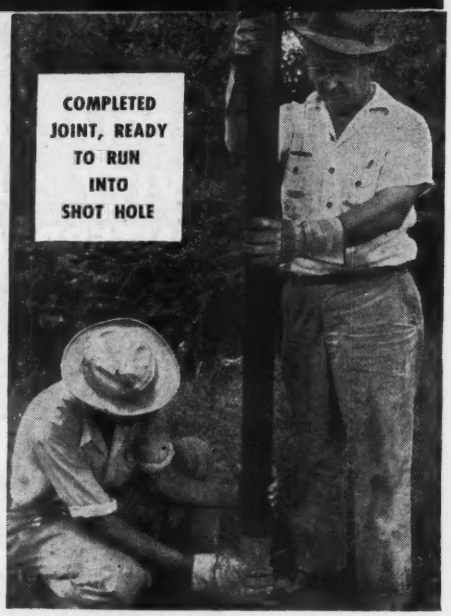

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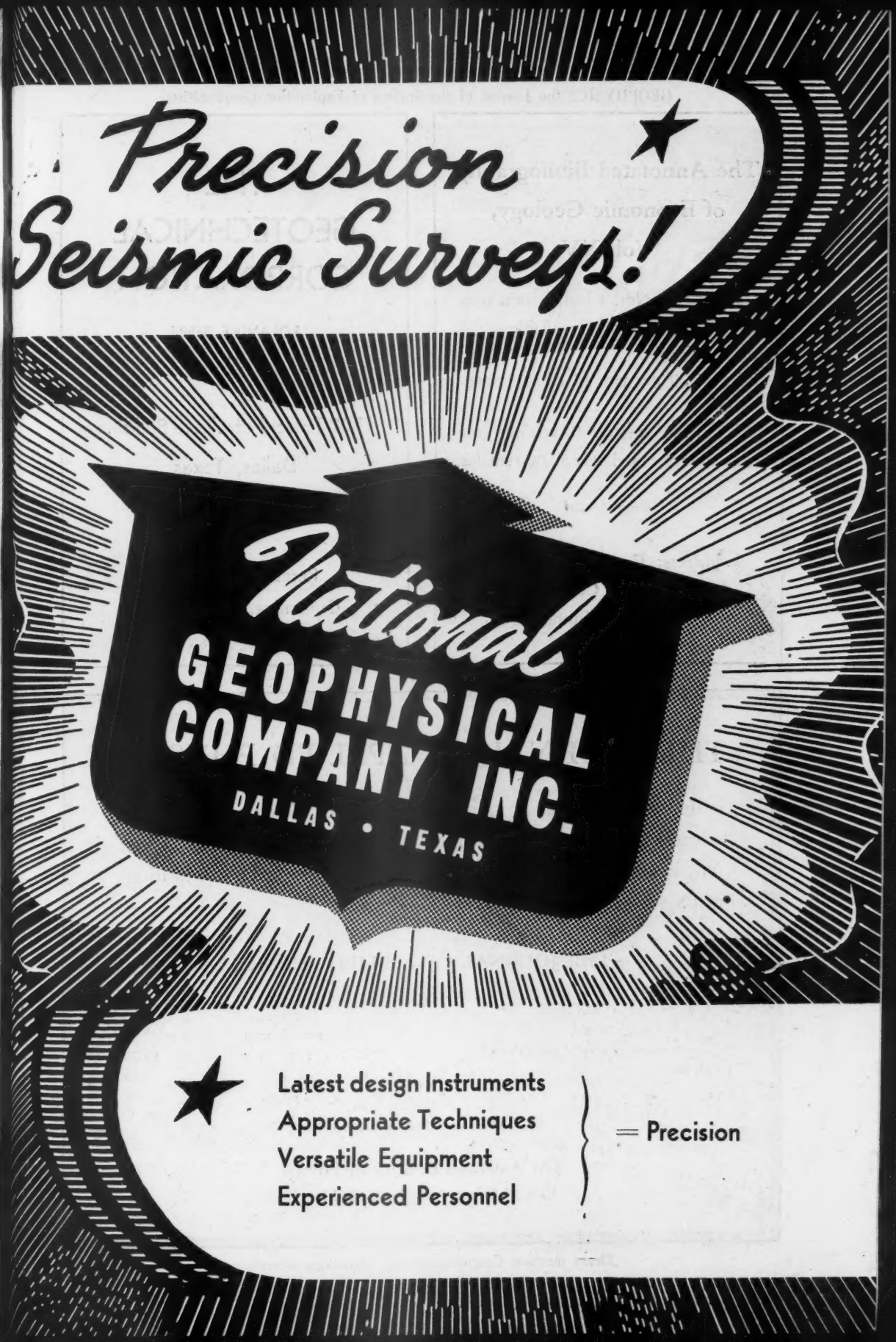
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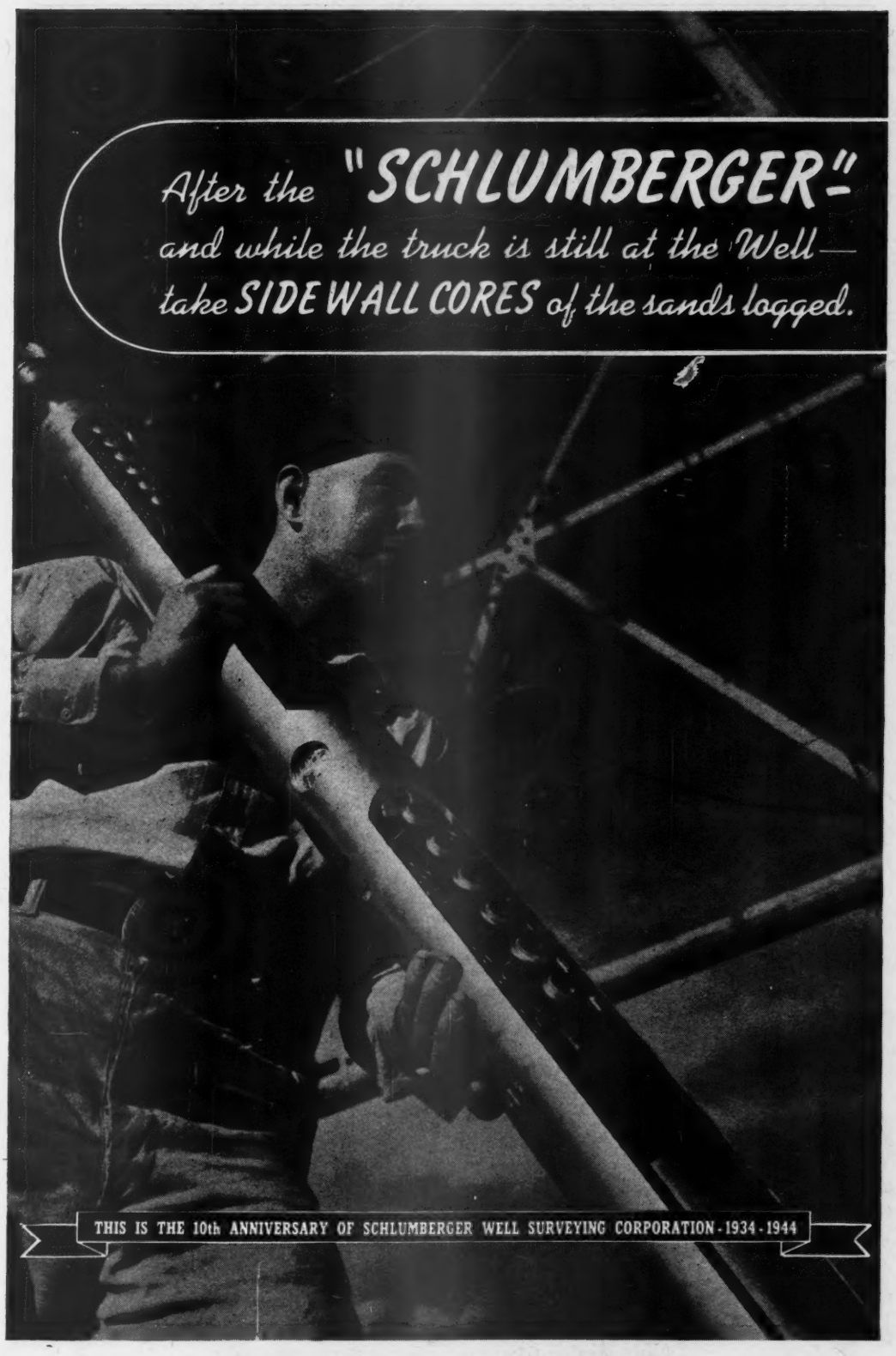
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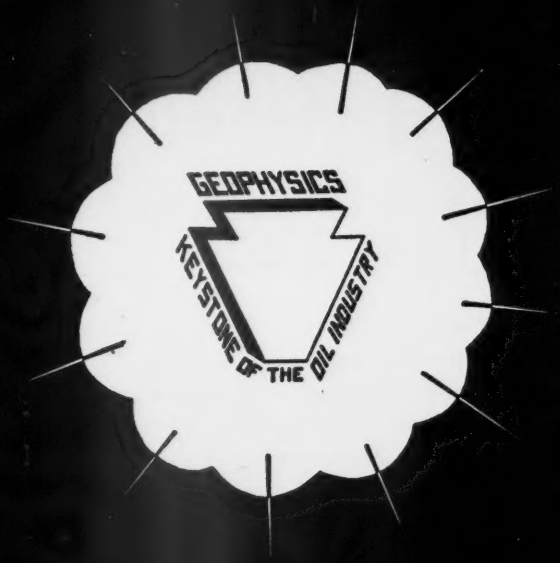

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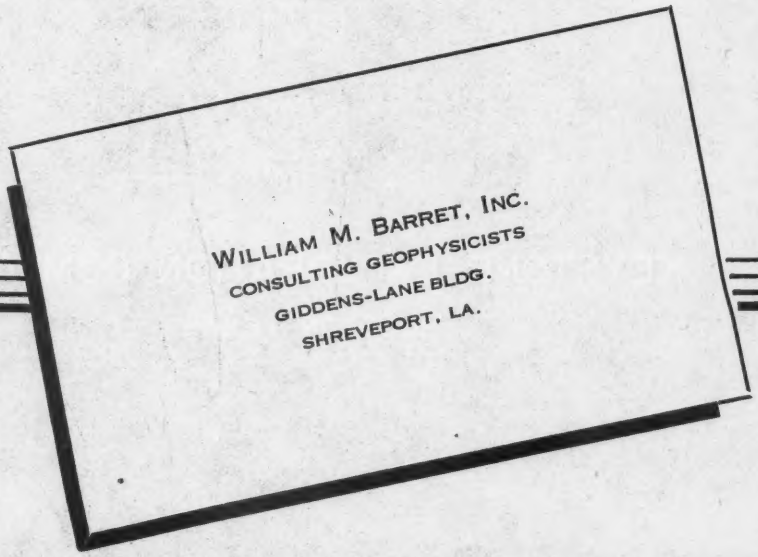

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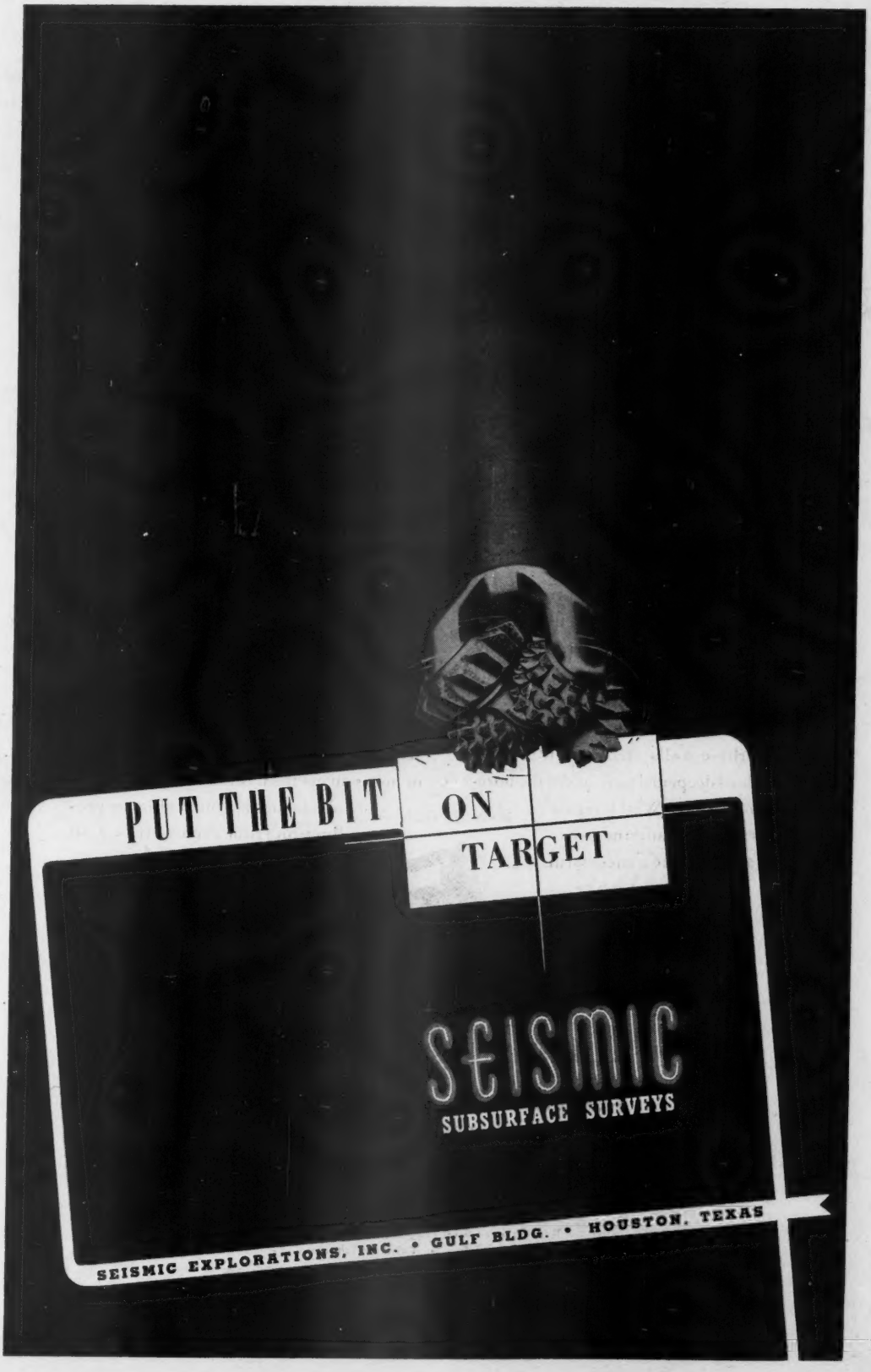
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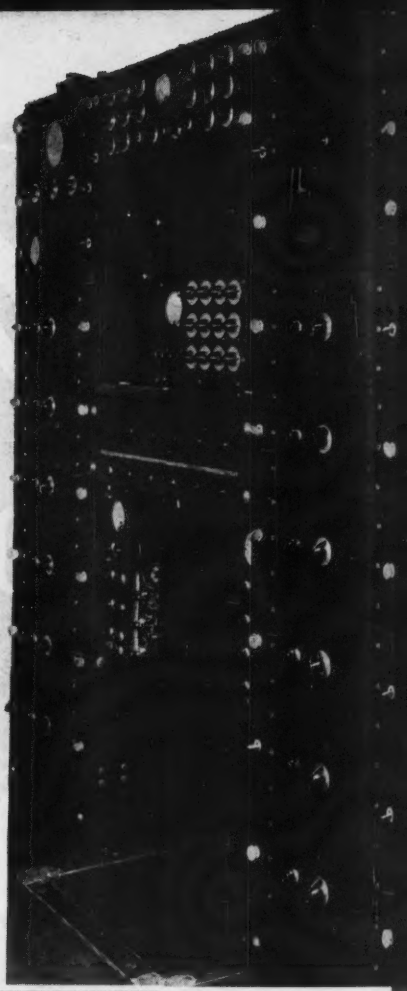

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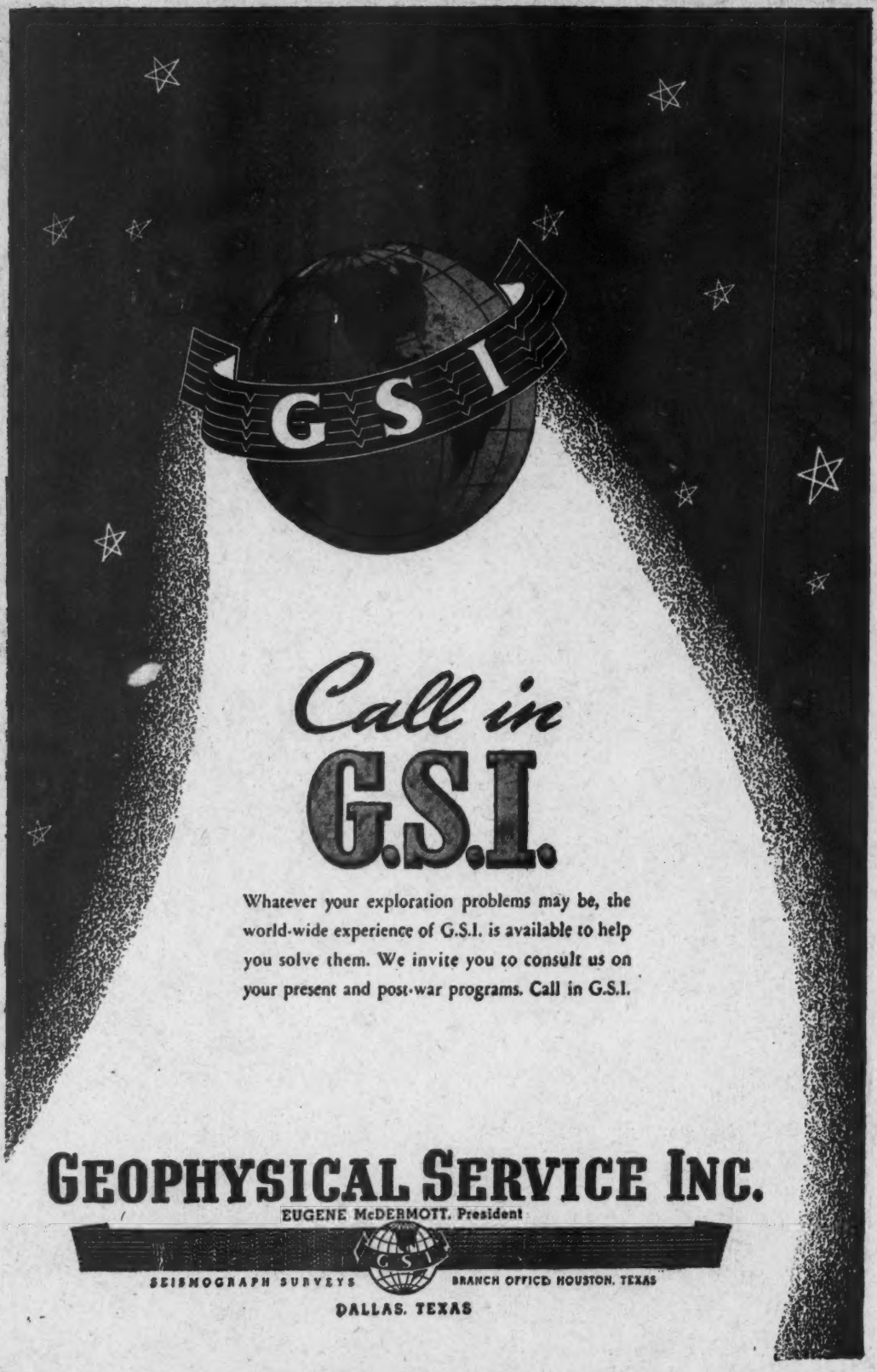

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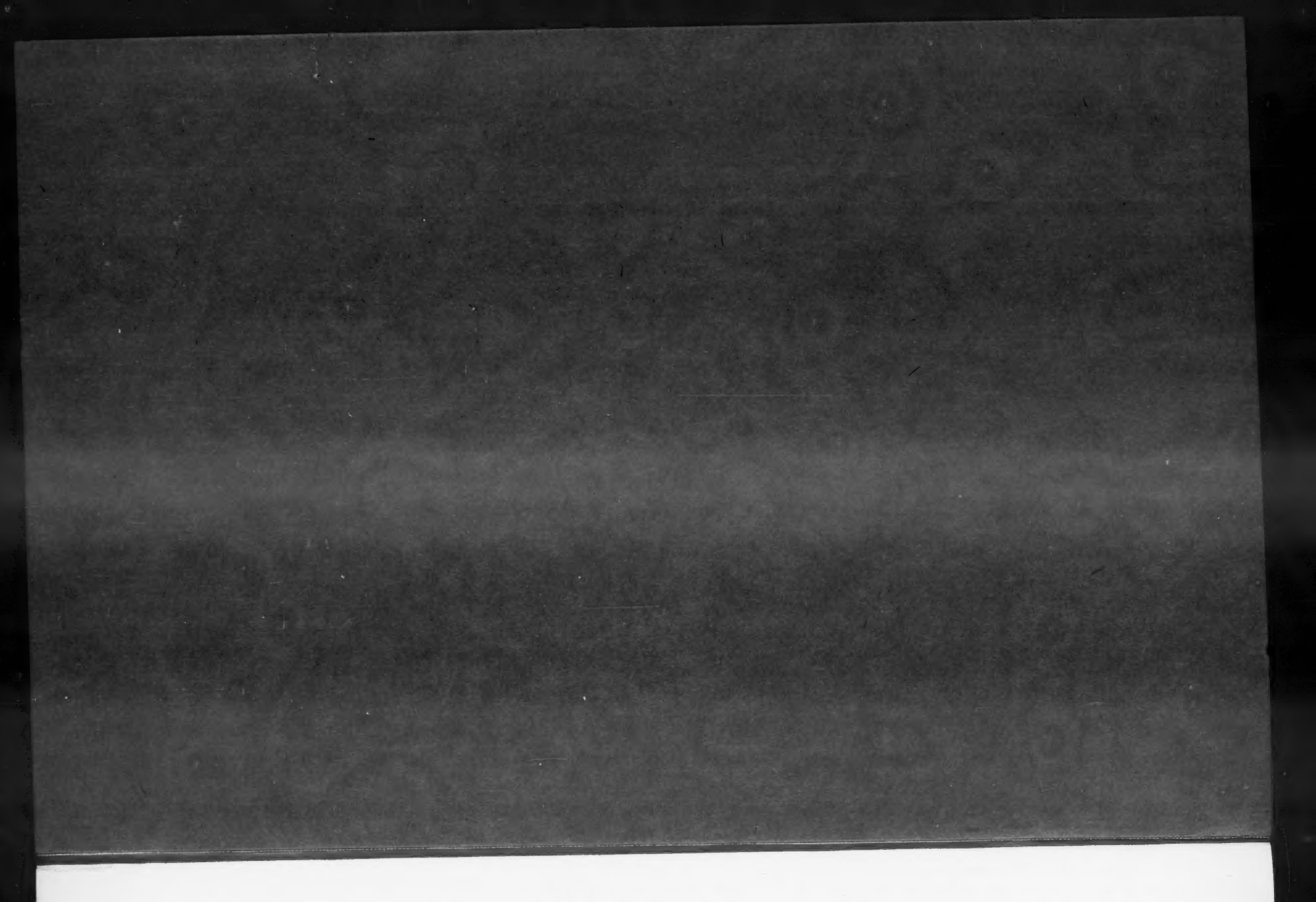
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